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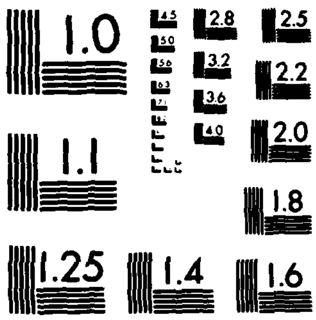
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AFWAL-TR-84-2070
Part I

AVIATION TURBINE FUELS FROM TAR SANDS BITUMEN AND HEAVY OILS

Part I Process Analysis

HF Moore, CA Johnson, WA Sutton, LM Henton and MH Chaffin

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SEPTEMBER 1984

Interim Report for Period 1 July 1983 - 31 March 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Phase I work performed was directed toward defining the United States tar sands and heavy oil resources by a literature survey and the development of a preferred processing route that would produce quantities of JP4 and JP8 at optimum operating conditions attaining at least 70% energy efficiency and limiting coke and residual products to less than 10 percent. The overall objectives from this program are to provide cost, yield, chemical and physical properties of variable quality aviation turbine fuels produced from tar sands and heavy oils.

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FOREWORD

This project was sponsored by the United States Air Force Wright Aeronautical Laboratories (AFWAL), Air Force Systems Command, under Contract No. F33615-83-C-2301. The work herein was performed during the period 1 July 1983 to 31 March 1984 under Program Element 63215F and Work Unit 24800802. The cognizant Air Force project engineer was Ms. Teresa Boos.

We are indebted to our Ashland colleague Mr. Robert E. Stone for his valued assistance in the computer modeling of Ashland's proposed process.

We must also give recognition to Ms. Sherry M. Connor for her valued assistance in preparation of this report.

This report is Part I of three parts. These parts correspond to the three phases of work which have been planned and will describe Ashland's effort during this contract.

The primary objectives of Part I are to define the United States tar sand and heavy oil resource by literature survey, development of a preferred processing route, and evaluation of the preliminary process economics.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACS	American Chemical Society
AICHE	American Institute of Chemical Engineers
AOI R&D	Ashland Oil, Inc., Petroleum Research and Development Department
°API	American Petroleum Institute liquid gravity scale
ART^{sm}	Asphalt Residual Treatment, a licensed service mark of Engelhard Corporation.
BBL	barrels, 42 US gallons
BPCD	barrels per calendar day
BPD	barrels per day
BuMine	Bureau of Mines, U.S. Government
CE	Chemical Engineering Magazine
concarbon	Conradson carbon
cps	centipoise
C_3	propane
C_4	butane
C_5	pentane
DCF	discounted cash flow
DF-2	diesel fuel
DOD	United States Department of Defense
DOE	United States Department of Energy
ed	edition or editor
eff	efficiency

LIST OF SYMBOLS AND ABBREVIATIONS (CONT'D)

EPA	Environmental Protection Agency, U.S. Government
est.	estimated
°F	degrees Fahrenheit
FCC	fluid catalytic cracker or cracking
FOE	fuel oil equivalent
ft.	feet
Grav.	gravity
HDS	hydrodesulfurization
HF	hydrogen fluoride
H/C ratio	hydrogen to carbon weight ratio
IC_4	isobutane
IGT	Institute of Gas Technology
JP-4	MIL-T-5642K jet fuel
JP-8	MIL-T-83133 jet fuel
K factor	Watson K factor, defined as the cube root of the volumetric average boiling point, in °Rankine, divided by the specific gravity.
kw	Watson K factor
KwHr	Kilowatt-Hour
LETC	Laramie Energy Technology Center (now Western Research Institute)
LP	linear programming

LIST OF SYMBOLS AND ABBREVIATIONS (CONT'D)

LPG	liquified petroleum gases
M	thousand
MM	million
m	meter
m^3	cubic meter
md	millidarcies
MGT	management
MM	million
NC_4	normal butane
No.	number
NPRA	National Petroleum Refiners' Association
NTIS	National Technical Information Service (U.S. Government)
OP.	operation
ppm	part per million (by weight unless specified)
PREP.	preparations
psi	pounds per square inch pressure
P.V.	pore volume
RCC^{sm}	Reduced Crude Conversion, a service mark of Ashland Oil, Inc.
ROSE^{sm}	Residual Oil Supercritical Extraction, licensed by Kerr-McGee, Inc.
RPT	report
sq.	square
USAF	United States Air Force

LIST OF SYMBOLS AND ABBREVIATIONS (CONT'D)

visc.	viscosity
vol	volume
WBS	work breakdown structure
wt	weight
2nd	second
10^9	billion
10^6	million
<	less than
>	greater than
@	at
%	percent
°	degrees
( )	byproduct credits when used in economic value tables

SECTION I

INTRODUCTION

During the past two decades, energy resources have been shown to be critical to world and United States economic development and well-being. Energy supplies have been extremely cyclic in relation to demand during this period. The world has moved from adequate supplies during the sixties, to thoughts of rationing in the early 70's, through adequate though tight supplies in the middle seventies, to limited supply and gasoline lines in the late 1970's, to overcapacity during the early 1980's. These swings in the supply/demand relationship have been particularly damaging to the United States, due to a high level of imported oil and volatile price structures.

Developing secure domestic energy resources is, and should be, a high priority for domestic security reasons as well. Table 1 summarizes the problems faced by users of aviation turbine fuels. Federal programs to develop coal and oil shale resources are well known; noteworthy within this framework are earlier studies funded under Department of Defense (DOD) auspices.[1-7] The major resource further available is tar sands bitumen and/or heavy oil. Attention has been brought to bear on this potential energy supply by recent DOD research contracts[8] awarded to Suntech and Ashland Oil for evaluation of refining methods applied to these resources.

TABLE 1

STATEMENT OF THE PROBLEM

- DISAPPEARANCE OF PARAFFIN BASE LIGHT CRUDES
- USE OF HEAVIER SOUR CRUDES
- COMPETITION FOR NAPHTHA FRACTION BY GASOLINE PETROCHEMICALS AND PLASTICS
- DEPENDENCE UPON OVERSEAS SOURCES FOR SUBSTANTIAL CRUDE SUPPLY

On July 1, 1983, the Research and Development Department of Ashland Petroleum Company (a division of Ashland Oil, Inc.) began work under Contract F33615-83-C-2301, "Turbine Fuels from Tar Sands Bitumen and Heavy Oils." The objective of this program is to determine the cost, yield, chemical properties, and physical characteristics of variable quality aviation turbine fuels produced from tar sand bitumen and heavy oil crudes. Attainment of this objective is planned to be accomplished by adaptation of the Ashland Oil, Inc., RCC^{sm} Process technology and other process technologies as necessary to produce optimum product slates.

This program keys on six major goals:

- Optimize the Processing Scheme
- Produce Sample Quantities of JP 4 and JP 8
- Achieve at least 70% Energy Efficiency
- Limit Coke and Residual Products to Less than 10%
- Develop an Economic Model of Process
- Determine the Economic Effect of Varying Fuel Quality

These goals are to be addressed in three major phases of activities:

Phase I. Preliminary Process Analysis

Phase II. Laboratory Sample Production

Phase III. Pilot Plant Testing, Final Design and Analysis

These activities are scheduled to be performed sequentially

over a total period of twenty-four months.

This report summarizes results obtained during Phase I, which was performed during the period July, 1983, through March, 1984. Primary elements of this study are (1) definition of the United States tar sand and heavy oil resource by literature survey, (2) development of a preferred processing route, and (3) evaluation of the preliminary process economics.

II. RESOURCES AND MATERIAL PROPERTIES

Tar sands bitumen and heavy crude oils are a major potential energy source. These materials, though widespread, are poorly understood. In fact, no common definition of these materials is readily available, although an excellent set of descriptive criteria has been presented by Meyer[9]:

1. Low API gravity (<20°API)
2. Poor reservoir mobility
3. Viscosities greater than 60 centipoise
4. Dark color
5. Metals as high as 500ppm
6. Sulfur content 3 weight percent or higher
7. Asphaltene content up to 50 weight percent
8. High thermal sensitivity
9. Frequent occurrence of water-wettable particulates

Byramjee[10] has presented a set of criteria for distinction between bitumen and heavy oils, Figure 1. For the most part, discussions in this report will use these definitions, although the distinction between each class is not as clear as the criteria indicate.

Heavy crudes are found throughout the world, in deposits of varying magnitude. Deposits in Canada and Venezuela represent the majority of the volume in place among these deposits, Table 2. Production from these heavy oil sources

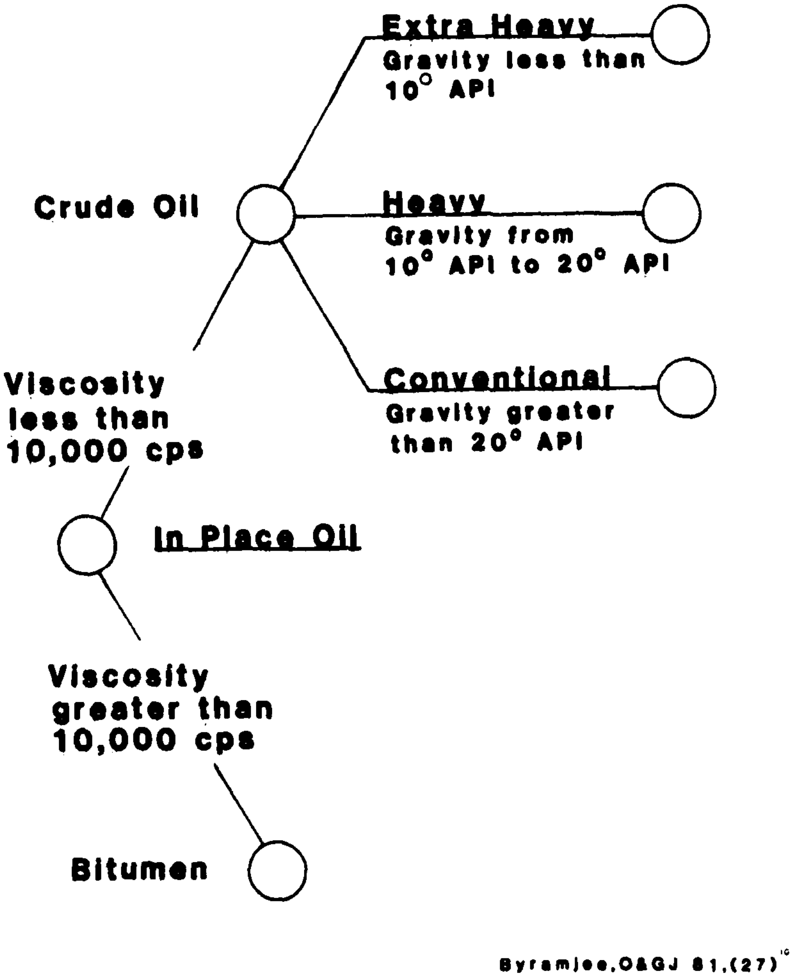


FIGURE 1. OIL NOMENCLATURE CRITERIA

TABLE 2.

WORLD OIL IN PLACE -- Estimated

TOTAL HYDROCARBONS :

5,000 X 10^9 BBL CONVENTIONAL

6,000 X 10^9 BBL HEAVY OIL AND BITUMEN

HEAVY OIL AND BITUMEN IN PLACE:

VENEZUELA	38%
CANADA	22%
U.S.S.R.	22%
NIGERIA AND MEXICO	8%
U.S.A.	3%
ALL OTHERS	7 %

Meyer, et.al "World Resources of Heavy Oil and Tar Sands", Synthetic Fuels From Oil Shale and Tar Sands (1983)[12]

is reported[9] to be about 5 percent of total annual world crude production. However, this production is commonly of those crudes nearer the 20°API definition, and much of this production is used in high dilution with lighter crudes. An excellent example is the previous Mexican practice of selling fixed ratios of light Isthmus with heavy (22°API) Mayan crudes. Direct use of truly heavier crudes (10°API or less) and bitumen is very small at present. The incentive to develop these sources is obvious, as there are potentially as much heavy oil and bitumen available as present conventional crude.

Of particular interest are the reserves of these materials in the United States. The distribution of tar sand bitumen and heavy oils is summarized in Figure 2, with the major known resources in Utah, California, Texas and Kentucky. In-place resources for the United States may be as much as 120-200 billion barrels of heavy oils (primarily in California) and more than 50 billion barrels of bitumen. This in-place estimate is based on conversion of reserves at an estimated recovery factor of about 10 percent. A recent estimate of bitumen locations is shown in Figure 3; the speculative resources for Alaska and Alabama are particularly intriguing. A summary of these resources by states is presented below.

Summary oil properties are also presented in the following section, with both data ranges and average or "judged typical" values reported. Caution should be observed when

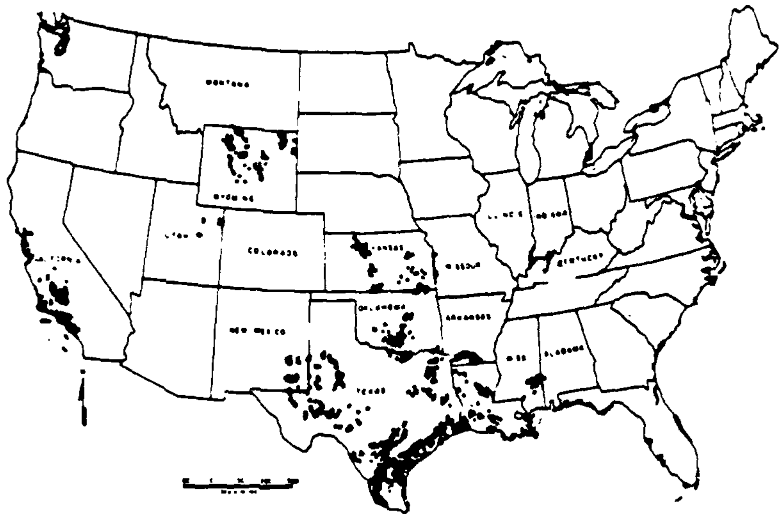


FIGURE 2.
Heavy Oil Deposits in the U.S.[9]

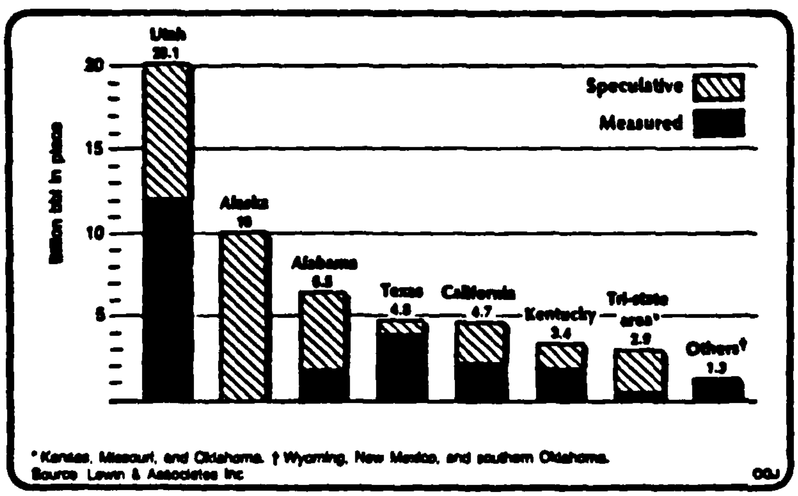


FIGURE 3.
Distribution of U.S. tar sand resources[13]

using these values, as they are very sensitive to the production method used in recovering the oil. They are not in-place bitumen properties, but rather the properties which a refiner might expect to see at the upgrading facility. As a result, both the data average and range are of importance in evaluating material values.

UTAH

Twenty-four states in the United States contain tar sand deposits. About 90 to 95 percent of the mapped resource is located in Utah, where Ritzma and Campbell[14] estimate a total of 29 billion barrels of oil in place. There are about 53 defined deposits of oil-impregnated rock in Utah. Figure 4 shows the largest of these deposits. Twenty-five deposits have been found in the Uinta Basin and twenty-two in the central southeast region. Six minor deposits are widely scattered in the northwest, southwest, and far southeast parts of the state. Although occurrences of bitumen saturation up to 17 weight percent can be found in Utah tar sand, current information indicates that the saturation for most reserves in Utah falls in the range of five to ten percent.

Five of these 53 deposits account for the majority of Utah tar sands reserves. These five major deposits, Tar Sand Triangle, P.R. Spring, Sunnyside, Asphalt Ridge, and Hill Creek, account for about 90% of the total measured domestic tar sands resource. Three of these five, Asphalt Ridge, Hill

Creek, and P.R. Springs are located in the Uinta Basin. Sunnyside is located just to the Southwest of the Uinta Basin. Tar Sand Triangle lies in southeast Utah in remote and very rugged terrain. Features of these deposits are summarized in Table 3.

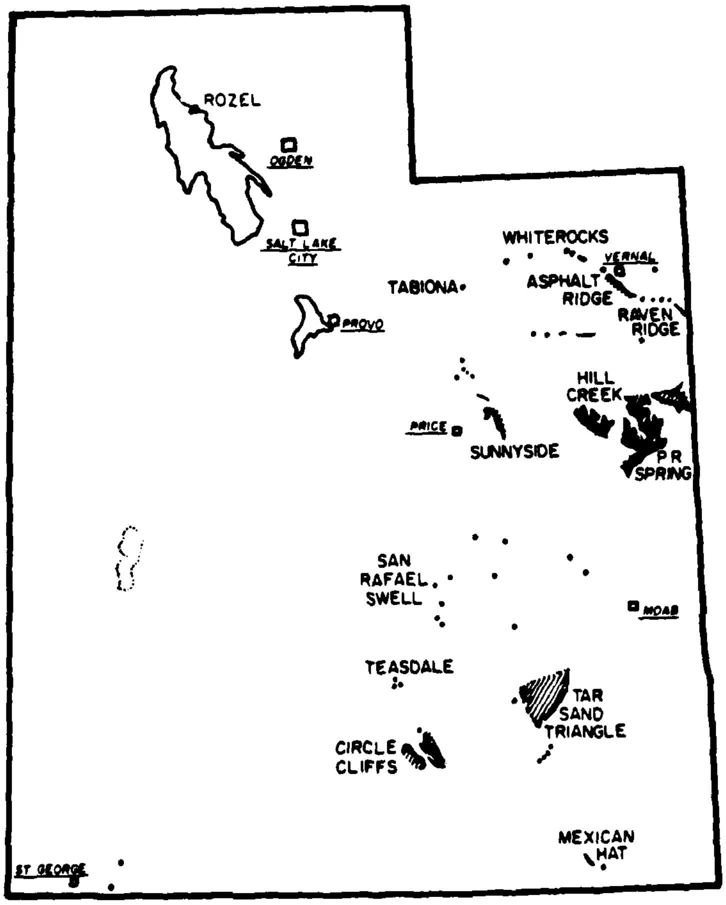


FIGURE 4.
UTAH TAR SANDS

Baughman, Synthetic Fuels Data Handbook, 2nd ed., 1978[15]

Uinta Basin

Twenty-four of the twenty-five deposits in the basin contain oil which originated in the rich organic sediments of the

Paleocene-Eocene Wasatch and Green River formations. The Green River Formation also contains very extensive oil shale, and the Wasatch and Green River are the sources of major

Table 3 CHARACTERISTICS OF UTAH'S MAJOR TAR SANDS[16]

	Average Values					Ranges, () - No. of Samples, () - Average Value					
Deposit	Porosity % P.V.[b]	Permeability, md	Bitumen sat., % P.V.	Water sat., % P.V.	Compressive strength, psi	Areal Extent (sq. miles)	No. of pay zones	Gross thickness of pay (Stratigraphic range, ft.)	Overburden Thickness (feet)	Gravity °API	Gallons/ Ton
Asphalt Ridge	19.6	497	51.4	2.7	2,491	20-25	2-5	10-135	0-500+	8.6-17.5 (4)	13-27 (6)
Hill Creek	20.2	325	29.7	2.1	6,555	115-225	6-13 (3)	53-65 (61)	0-500+	5.5-10.5 (5) (7.9)	1.0-21.2 (129)
P. R. Spring	25.0	1,510	42.5	3.0	4,784	240-270	1-13 (13) (7)	10-102 (39)	0-500+	5.8-10.3 (37)(9.5)	0.2-30.5 (454)
Sunnyside	21.3	729	44.8	-	7,805	35-90	1-12	15-550	0-500+	6.2-6.7 (2)	-
Tar Sand Triangle	20.0[c] 19.7	207[c] 788	6.3[c,d] 70.7	- -	3,242[c] -	200-230	1	5-300	0-1600+	-3.6-9.6 (5) (+4.5)	4.9-13.7 (5)(9.3)

(a) All values based on samples from cores except as indicated.
(b) P. V. = pore volume.
(c) Surface samples.
(d) Total liquid saturation percent by weight.

deposits of solid hydrocarbons, notably gilsonite. The Split Mountain deposit is the only deposit in the Unita Basin which definitely contains Paleozoic oil in Permian rocks.

A list of named Uinta basin tar sand deposits is given below, along with some in-place oil estimates.

Table 4

Uinta Basin Deposits

Deposit	MMBBL
Argyle Canyon	50-75
Asphalt Ridge	1,048
Asphalt Ridge N.W.	100-125
Chapita Wells	7.5-8
Cottonwood-Jack Canyon	20-25
Cow Wash	1-1.2
Daniel's Canyon	-
Hill Creek	1,160
Lake Fork	6.5-10
Littlewater Hills	10-12
Minnie Maud Creek	10-15
Nine Mile Canyon	5-10
Pariette	12-15
P. R. Springs	4,000-4,500
Raven Ridge	75-100
Rim Rock	25-30
Split Mountain	-
Spring Branch	1.5-2
Spring Hollow	-
Tabonia	1.3-4.6
Thistle	2.2-2.5
Upper Kane Hollow	-
Whiterocks	65-125
Willowcreek	10-15

Asphalt Ridge

Asphalt Ridge, a few miles from Vernal in easy terrain, has long been recognized as the most accessible deposit in the United States. It is no coincidence that the first mining and in-situ projects in Utah in the 70's got underway there. The tar sand deposits occur in the Duchesne River Formation

of Eocene Age and the Rimrock Sandstone member of the Mesaverde Formation of Upper Cretaceous Age. The areal extent of the deposit is between 20 and 25 square miles. There are from two to five separate pay zones more than five feet thick. The total thickness of all pay zones varies from ten to 135 feet. The oil in place reserve totals 1,048 million barrels. Of this, 435 million are measured, 438 million are indicated, and 175 million are inferred. The pay zones dip 8 to 30 degrees to the southwest averaging 10 degrees according to Glassett and Glassett[17] and 9 to 35 degrees according to Campbell and Ritzma[14]. About twelve percent of the Asphalt Ridge deposit is surface mineable.

Advantages of Asphalt Ridge deposits are:

(1) favorable accessibility to facilities and product markets

(2) good oil saturation

(3) good pay thickness

(4) excellent water availability

(5) low sulfur content

(6) minimal land ownership problems

Reported properties for Asphalt Ridge bitumen vary widely. Gravities ranging 7.8-20.3° API, hydrogen contents 10.5-13.0%, and carbon residue 3.5-15.1 wt.% have been identified in the literature. At present, however, our judgement is that about 12-13° API, 11%+ hydrogen, 1.1%

nitrogen, 0.4% sulfur, and 8% carbon residue should be a reasonable average (Table 5). This material could be a reasonably good upgrading feedstock.

Tar Sand Triangle

The Tar Sand Triangle is the largest accumulation of tar sands in Utah. It is estimated to cover an area of 230 square miles and may contain from 3 to 16 billion barrels of oil. The actual resource quantity is presently under debate.

The oil in the deposit apparently originated in organic Permian or possibly Pennsylvania rocks. Later, the oil migrated upward via faults, fractures, and joints and penetrated into the uppermost Permian and lower Triassic sandstones. The formation of the canyons on each side of the deposit resulted in the formation of outcrops on both the updip and downdip sides of the huge deposit. Erosion released the lighter hydrocarbons to the atmosphere while the heavier hydrocarbons migrated downward due to gravity.

Little public data exist on the deposit at this time and the characteristics of the deposit are only partly defined. The most favorable characterizations indicate net pays of up to 300 feet, averaging 150 feet, with a porosity of 26 percent and oil saturation of 70%. However, other appraisals indicate that the deposit consists of numerous thin pay zones within a thick gross interval having porosities of under 20 percent

TABLE 5

UINTA BASIN, UTAH PROPERTIES

Asphalt Ridge Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API (@60°F)	13.3	7.8 - 20.3
Specific Gravity	0.977	1.02 - 0.93
Carbon, WT% (Ash Free)	85.8	85.2 - 86.7
Hydrogen	11.5	10.5 - 13.0
Nitrogen	1.1	0.82 - 1.44
Sulfur	0.4	0.14 - 0.77
Oxygen	1.1	0.85 - 1.6
Metals, ppm (Ash Free)		
Iron	---	No Data
Nickel	90	45 - 120
Vanadium	30	5 - 115
Sodium	---	No Data
Ash, WT%	0.04	0.04 (2)
Carbon Residue, WT% (Ash Free)	8.0	3.5 - 15.1
Viscosity, cp @		
77°F	3×10^6	2.2×10^6 - 6.93×10^6
100°F	4.4×10^5	4.2×10^5 - 2.0×10^6
210°F	3000	1700 - 15,000
275°F	325	270 - 350
Pour Point, °F	130	25 - 150
Compound Types, WT%		
Asphaltene	9	3.4 - 11.8
Saturates	32	25.7 - 48
Aromatics	25	18 - 28.4
Polars	33	22 - 46
Distillation, Vol% @		
600°F	6	0.5 - 23.3
1000°F	45	40 - 58
K Factor	11.7	11.2 - 11.8

and oil saturation of under 50%. At present the resource is best described as moderately rich to very lean.

Literature values suggest that this material is a low API gravity, low hydrogen, high sulfur material with a high carbon residue. Major properties suggest an aromatic character (Table 6).

Sunnyside

Sunnyside is the largest and best exposed of several deposits located just southwest of the Uinta Basin. Most of the oil saturation occurs in the upper third of the 3700 foot thick Wasatch Formation of Lower Eocene Age. Some saturation occurs in the lower overlying beds of the Green River Formation of Middle Eocene Age. There are from 3 to 12 pay zones that vary from 10 to 350 feet in thickness with a 1,000 foot interval between the 9,000 and 10,000 feet elevations. The outcropping beds dip gently northeastward into the Uinta Basin at angles from 3 to 10 degrees.

The areal extent of the deposit is between 35 and 90 square miles. The quantity of oil in place is estimated to be between 3.5 and 4.0 billion barrels of which 1.25 are measured, 1.75 are indicated, and the balance inferred.

The deposit ranges from very rich, thick sections of oil saturation to thin and essentially barren pays. The better

TABLE 6

CENTRAL SOUTHEAST UTAH PROPERTIES

Tar Sands Triangle Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API	7.0	-3.6 to 11.1
Specific Gravity	1.02	1.11 - 0.99
Carbon, WT% (Ash Free)	84.4	84.0 - 85.2
Hydrogen	10.3	9.1 - 11.8
Nitrogen	0.53	0.3 - 0.7
Sulfur	4.10	2.5 - 6.27
Oxygen	1.4	1.1 - 1.7
Metals, ppm (Ash Free)		
Iron	----	No data
Nickel	62	53 - 70
Vanadium	151	108 - 194
Sodium	----	No data
Ash, WT%	0.1	0.1
Carbon Residue, WT% (Ash Free)	20	17.0 - 21.6
Viscosity, cp @		
77°F	1.3×10^6 (@ 70°F)	1.3×10^6 (@ 70°F)
100°F	----	----
210°F	----	----
275°F	----	----
Pour Point, °F	95	95
Compound Types, WT%		
Asphaltene	26	26(2)
Saturates	34	25.7 - 42
Aromatics	27	22 - 31.9
Polars	13	10 - 16.4
Distillation, Vol% @		
600°F	11	6.7 - 15.9
1000°F	44	40 - 57.6
K Factor	11.4	11.2 - 11.6

parts of the deposit, essentially in the center portion of the deposit, have net pays of 50 to 100 feet, oil saturations of 60 percent and porosities of 25 to 30 percent. The less favorable portions are generally located at the edges of the deposit and in pay zones above and below the better sections. They have numerous thin tar bearing intervals within thick gross intervals, low oil saturation ranging from barren to 30 percent, and porosities of 16 to 25 percent. The better segments of the deposit have considerable overburden, ranging from 300 to over 1000 feet.

Oil produced from this deposit (Table 7) has a low API gravity, good hydrogen content, low sulfur and high nitrogen level. Carbon residue is high, while metals are moderate. The characteristic Uinta basin property of higher nickel than vanadium content is also observed.

P.R. Springs

The P.R. Springs deposit, located in the southeastern part of the Uinta Basin, encompasses an area of 350 square miles. The resource occurs in the upper part of the Douglas Creek Member of the Green River Formation, immediately below the oil-shale bearing Parachute Creek Member. Regional dip is northwesterly at 2°-4°.

The deposit contains an estimated 4-4.5 billion barrels of oil in place, making the deposit second in size after the Tar

TABLE 7

UINTA BASIN, UTAH PROPERTIES

Sunnyside Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API (@60°F)	9.3	6.7 - 12.9
Specific Gravity	1.005	1.024 - 0.980
Carbon, WT% (Ash Free)	86.3	84.1 - 86.3
Hydrogen	11.1	11.1 - 11.6
Nitrogen	0.94	0.8 - 1.0
Sulfur	0.45	0.3 - 0.6
Oxygen	1.2	1.4
Metals, ppm (Ash Free)		
Iron	200	200
Nickel	85	60 - 140
Vanadium	20	10 - 30
Sodium	---	---
Ash, WT%	3.0	0.4 - 9
Carbon Residue, WT% (Ash Free)	16	14.1 - 19.1
Viscosity, cp @		
77°F	2.2×10^7	1.8×10^7 - 1.5×10^9
100°F	3.1×10^6	2.2×10^6 - 3.1×10^6
210°F	6000	5000 - 6000
275°F	700	646 - 700
Pour Point, °F	>115*	115
Compound Types, WT%		
Asphaltene	20	20 - 23
Saturates	40	40
Aromatics	15	15
Polars	25	25
Distillation, Vol% @		
600°F	5	0.5 - 5.5
1000°F	36	34.1 - 37.0
K Factor	11.3	11.2 - 11.7

*Recommend 140°F

Sand Triangle deposit. Of this estimate 2.5 are measured, 1.2 indicated and the balance inferred. Core samples indicate poor pay thickness and wide separation of the two to six pay zones by barren material.

The PR Springs bitumen resembles the Sunnyside material, but it may have a slightly lower pour point and carbon residue (Table 8).

Hill Creek

The Hill Creek deposit is estimated to contain 1.2 billion barrels of oil of which 350 million are measured, 480 are indicated, and 330 are inferred. It covers an area of from 115 to 125 square miles. There are from one to three pay zones that vary from five to thirty-five feet in thickness. Overburden thickness varies from none at the outcrops to more than 500 feet.

Core samples indicate that the pay consists of a series of up to 10 foot saturated intervals separated by unsaturated or poorly saturated sandstone. The deposit appears to be relatively lean with limited continuity in the pay.

CALIFORNIA -- Tar Sands

There are six major tar sand deposit areas in California, each containing in excess of one million barrels of bitumen. These deposits are Casmalia, Edna, McKittrick, Point Arena,

TABLE 8

UINTA BASIN, UTAH PROPERTIES

P. R. Springs Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API (@60°F)	10.3	5.7 - 16.5
Specific Gravity	0.998	1.031 - 0.956
Carbon, WT% (Ash Free)	85.5	84.4 - 88
Hydrogen	10.7	10.4 - 11.05
Nitrogen	1.1	0.67 - 1.8
Sulfur	0.5	0.22 - 0.75
Oxygen	2.2	2.2
Metals, ppm (Ash Free)		
Iron	---	No Data
Nickel	108	98 - 120
Vanadium	35	25 - 56
Sodium	---	No Data
Ash, WT%	0.17	0.17
Carbon Residue, WT% (Ash Free)	13.0	11.0 - 15.8
Viscosity, cp @		
77°F	1×10^7	1.6×10^5 - 3.25×10^7
100°F	7×10^5	1×10^5 - 1.3×10^6
210°F	800	250 - 1320
275°F	185	185
Pour Point, °F	115	115
Compound Types, WT%		
Asphaltene	14	11 - 16
Saturates	27	25.7 - 29
Aromatics	25	24.9 - 25
Polars	34	35
Distillation, Vol% @		
600°F	5	2.0 - 7.1
1000°F	36	30.4 - 59
K Factor	11.5	11.35 - 11.8

Santa Cruz and Sisquoc. The estimated distribution is:

Table 9. Estimated California Tar Sand Distribution[18]

	Estimated Resources (Millions of Barrels)	
	Low	High
Oxnard	565.0	
Santa Maria	500.0	2,000.0
Edna	141.4	175.0
South Casmalia	46.4	
North Casmalia	40.0	
Richfield	40.0	
Paris Valley	30.0	100.0
Sisquoc	29.0	106.0
Santa Cruz	10.0	
McKittrick	4.8	9.0
Point Arena	1.2	
CALIFORNIA TOTAL	1,407.8	3,092.6

The locations of these deposits are shown in Figure 5.

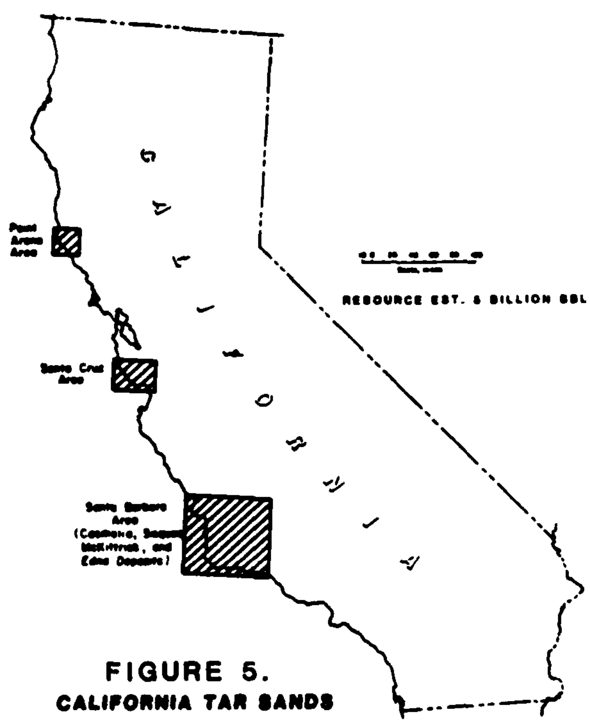


FIGURE 5.
CALIFORNIA TAR SANDS

Baughman, Synthetic Fuels Data Handbook, 2nd ed., 1978

The California oil sand deposits are relatively rich, averaging approximately 12 weight percent oil. The richest deposit is the North Casmalia located in Santa Barbara County. Saturation in this area has been observed to be as great as 18 weight percent. Bitumen saturation in the largest deposit, Edna, in San Luis Obispo County, ranges from 9 to 16 weight percent.

Oxnard Oil Field - Vaca Tar Sands[19]

The Oxnard oil field is located in the Oxnard Plain in southern Ventura County, east of the city of Oxnard. Oil production in this field is obtained from several zones that range in depth from 1,800 to 10,000 feet. The shallowest zone is known as the Pliocene Tar. This zone contains two tar sands found at depth from 1,800 to 5,000 feet. The upper sand is known as the Vaca Tar Sand and the lower sand is known as the Lower Pliocene Tar Sand.

The Vaca Tar Sand is found at depths from 1,800 to 2,500 feet. The reservoir rock characteristics make the reservoir a good candidate for thermal enhanced recovery methods. However, the poor quality of this crude (5° to 8° API and 7.5% Sulfur) makes it difficult to refine and market competitively. The Vaca Tar Sand has a bulk volume of approximately 315,000 acre feet, and originally contained about 400 million barrels of oil.

The Lower Pliocene Tar Sand is found at depths of 2,800 feet to 5,000 feet. This sand is much thinner than the Vaca Tar Sand. The Lower Pliocene Tar Sand has an areal extent of 1,876 acres and an average thickness of 48 feet. The Vaca has 1,720 acres and an average thickness of 183 feet. The oil in place in the lower tar sand is about 165 million barrels.

Edna Area-Arroyo Grand[19]

The Edna deposit of San Luis Obispo County might be the largest surface occurrence of tar sand in California. It is located just north of Pismo Beach and a few miles south of San Luis Obispo City. The tar sands here are part of the Pismo Formation, which is from the early Pliocene and late Miocene age. Outcrops of tar sands occur throughout this area with the beds underlain by rich organic and petroliferous Monterey Shales. The total reserve is an estimated 250 feet deep with about 175 million barrels of oil in place.[19]

Santa Maria Valley - Foxen Tar Sand[19]

The Foxen Tar Sand lies at the base of the Foxen Formation and extends throughout a large area of the Santa Maria Valley. The tar sand ranges in depth from 500 feet to 4,000 feet with an average net thickness of 100 feet. The deposit has an average porosity of 33 percent. Gravity of the oil in this sand ranges from 9° to 14° API.

The Foxen Tar Sand deposit in the Santa Maria Valley was discovered in 1934, but has never been fully exploited. A complete deposit evaluation could not be found, but the oil in place is estimated to range up to 2 billion barrels.

Sisquoc Area - Santa Barbara County[19]

The Sisquoc Area is about 20 miles southeast of Santa Maria. The deposit is in the Careaga Sandstone. The maximum thickness of the deposit is about 185 feet, with an average of 85 feet. The oil content of the Sisquoc is considered "high grade" at about 30 gallons per ton.

On the northern side of the Sisquoc River is another bituminous rock deposit. It has been estimated to contain over 79 million tons of mineable material.

Salinas Valley Area[19]

Tar Sand outcrops and seeps are found along the eastern edge of the Salinas Basin. The Salinas Basin contains a very thick section of Monterey Shale. In the deepest part of the basin, the Monterey is 12,000 feet thick. The Paris Valley and Bradley crudes are found here, with the Paris Valley Field estimated to contain about 100 million barrels of oil in-place. Thermal recovery attempts have been conducted but economic success has not been achieved. Total recovery from the Paris Valley Field as of January 1978 was only 97,000 barrels.

Richfield Tar Sand[19]

The Richfield Tar Sand is found within the Richfield oil field in Orange County, California. The sand has depths ranging from 2,500 to 3,200 feet and has a thickness of 80 feet. Data suggest that there are about 40 million barrels, with an API gravity of about 12°.

Santa Cruz Area - Santa Cruz County[19]

Several discontinuous outcrops of bituminous sandstone occur 4 to 6 miles northwest of the city of Santa Cruz. The oil impregnated beds vary in thickness from 1 to 35 feet, and range in quality from dry and brittle to saturated and gummy. Estimates suggest that about 9.8 million cubic yards of bituminous rock are in place containing about 9.5 million barrels of oil. This is approximately 10% bitumen by weight or 24 gallons per ton.

Point - Arena Area - Mendocino County[19]

Sandstone outcrops in the Monterey Formation in the Point Arena area contain approximately 15.6 gallons of oil per ton. This deposit of over 3 million tons of material contains an estimated 1.2 million barrels of oil.

McKittrick Tar Sands[19]

Asphaltic outcroppings near McKittrick California evidence the presence of oil bearing deposits. These outcroppings led to the discovery of oil in deeper sands in the Diatomite zone. These surface occurrences range from tar seeps to

sandstone outcrops saturated with bitumen. Veins up to 100 feet long and ranging in thickness from a few inches to eight feet are encountered on the surface and in bore holes. The material averages about 10% bitumen or 24 gallons per ton.

CALIFORNIA -- Heavy Oils

The distinction between California tars and heavy oils is gradual. Heavy oils are considered as having gravities from 10 to 20° API and tars are less than 10°API. With that in mind, five main areas of California producing heavy oils are the San Joaquin Valley, the L.A. Basin, the Santa Maria area, the Santa Barbara channel and the Santa Cruz-Monterey-Salinas Valley area. To date the San Joaquin Valley and L.A. Basin have produced the most heavy oil[9], but new large fields are being discovered in the Santa Maria (including offshore) and Santa Barbara channel areas.[20,21]

Both conventional and heavy oil are usually produced in all the areas mentioned above. The most important heavy oil areas are shown in Figure 6.

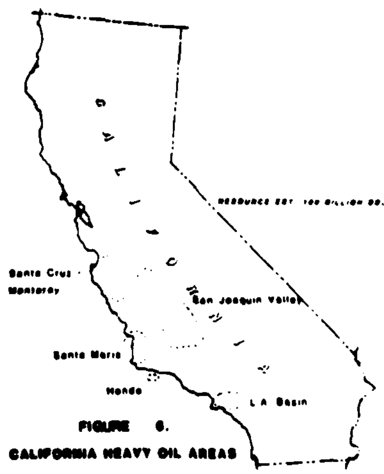


FIGURE 6.
CALIFORNIA HEAVY OIL AREAS

San Joaquin Valley - The Midway - Sunset, Kern River, Belridge, Poso Creek, and McKittrick fields produce heavy oil in the San Joaquin Valley area. Ultimate recovery of known and undiscovered heavy oil from the San Joaquin Basin is estimated at seven billion barrels.[12]

Many heavy oil enhanced recovery projects are active in the Midway-Sunset, McKittrick and Kern River fields. The oil ranges from 11-14°API and from <10,000 to 25,000 centipoise. The depth ranges from 600 to 2600 feet, with thicknesses ranging from 43 to 450 feet.[22]

The Kern River oil field lies 5 miles north of Bakersfield, in Kern County. The oil field occurs along a portion of the Bakersfield Arch. The productive intervals of the field are within the Plio-Pleistocene Kern River Formation, which consists of a thick series of lenticular sand bodies interbedded with mudstone and siltstone. The thickness of the Kern River Formation spreads from 700 feet in the east to 980 feet in the west, and is overlaid with up to 800 feet of unconsolidated gravel, sand, and silt. Oil gravities vary from 9 to 16° API, and viscosity from 400 to 7000 cp at 90°F.[23]

The Poso Creek field is located on the east San Joaquin Valley, 14 miles north of Bakersfield.

Present oil production is as a 12-13° API crude, obtained from three sandstone horizons between 1000 and 1400 ft. in the Etchegoin Formation of late Miocene and Pliocene age. The average net thickness is 100 feet with current oil saturation of 45 percent. Oil viscosity at 95°F is 3000 cp and reservoir pressure is 140 psi.[24]

Los Angeles Basin - Wilmington, Huntington Beach, West Newport, Placerita, Richfield, and Yorba Linda are fields that produce heavy oil in the Los Angeles Basin. Ultimate recovery of known and undiscovered heavy oil from the L.A. Basin is estimated at about 4.5 billion barrels.[12]

The Yorba Linda has produced oil 11-14° API oil from the La Habra formation at 500 feet depth with a 125 foot thickness and a 70% porosity.[22]

The Wilmington is one of the giant oil fields of the world, covering 13,000 acres near Los Angeles, with about 9 billion barrels of all types of oil in-place. The gravity of the crude ranges from 12 to 33° API, with the average at 17° API. Current production rate is close to 130,000 BPD.[25]

Sediments in the Wilmington oil field were deposited over an older schist beginning in Miocene time, with compression and deposit continuing through the Pliocene. The basement schist varies from 6000 to 8000 ft. deep, and the Wilmington

reservoir rocks are of two types. The lower type produces conventional gravity crude, but the upper type produces 12 to 20° API crude. The upper formations vary from loosely consolidated sand to unconsolidated "mush".[25]

The Wilmington basement schist is hot, which helps reduce the crude oil viscosity, allowing the heavy oil deposits to be produced as if they were higher gravity crude.[25]

Santa Maria Area - The Cat Canyon fields in the Santa Maria area have a number of projects producing heavy oil. Ultimate recovery of known and undiscovered heavy oil from the Santa Maria basin is estimated at 850 million barrels.[12]

The Cat Canyon fields have heavy oils ranging from 0 to 12° API, averaging 6-9° API produced. Depths range from 2000 to 6000 ft., with most in the 2500 to 3500 ft. range. The reservoir viscosities vary with API gravity from 1000 to 100,000 cp with produced oil usually about 15,000-20,000 cp. Oil is found in the Sisquoc and Brook formations of the Pliocene age.[22,26,27]

Offshore in the Santa Maria Basin heavy oils are found in the Miocene Monterey formation. North of Point Arguello,oil is produced at 10-14° API at depths of 2000-4000 ft. Reserves of the Point Arguello-Hueso reservoir are placed at 300-500 million bbl.[20]

Santa Barbara Channel - The Hondo, Pescado, and Sacate fields lie in the Santa Ynez unit more than 3 miles offshore in the Santa Barbara Channel. Production comes from two formations, with the heavy oil being in the top one. In the Hondo field, the Monterey crest at 9,000 ft. produces 11-21° API crude with 5% sulfur. The deeper sandstone at 11,000 ft. produces sweet crude at 36° API.[21]

Santa Cruz - Monterey - Salinas Valley Area - In the Salinas Valley, the San Ardo and King City fields are the two largest producers; other small fields are Monroe Swell, Quinado Canyon, McCool Ranch, Lynch Canyon, and Paris Valley. The small fields generally have more low gravity, high viscosity asphaltic crude.[19]

The Coastal and Santa Cruz basins are in this area; the Coastal is the largest (it includes San Ardo) with an ultimate recovery of known and undiscovered heavy oil estimated at about 740 million barrels.[19]

The San Ardo heavy oil is 12° API from 2000 to 2400 ft. deep with a viscosity of 2500 cp at 200°F. The McCool field produces 11° API gravity oil from 2150 ft.; Monroe Swell produces 18° API gravity oil from 2000-3200 ft.[26]

The Paris Valley field reservoir is in the Ansberry Formation at 840 ft. The reservoir temperature is 85°F and

estimated oil-in-place is 1568 barrels/acre foot. The heavy oil in the Lynch Canyon field has the reservoir in the Lanigan sand formation, with a temperature of 104°F.[28]

California Bitumen and Heavy Oil Properties

Properties of California heavy oils and tar sands bitumen vary widely as noted in the foregoing comparison. Average summaries are attempted in Table 10. Overall, these materials are probably naphthenic/aromatic stocks with the heavy oils having carbon residues less than 10 weight percent. Nitrogen contents are slightly higher than other materials evaluated except for the Uinta basin products. Sulfur values range from 0.2 to above 8 weight percent depending on the specific source.

WYOMING

Extensive information on Wyoming's bitumen and heavy oil deposits is scarce. However, Wyoming does have estimates of 350-550 million barrels of oil in-place, with reserves of 35 million barrels.[12] The heavy oil and bitumen deposits are found in two reservoirs, The Burnt Hollow Reservoir and The North Tisdale Lakota. The North Tisdale Field is characterized as conventional crude (28°API) by our definitions.
The Burnt Hollow Reservoir is located in the Minnelusa formation, with a depth from 600-1,200 feet. Contained oil, estimated at 930 bbl/acre foot, has a gravity of 9° API and a viscosity of one million centipoise. Porosity of this

TABLE 10

CALIFORNIA PROPERTIES SUMMARY

PROPERTIES	CALIFORNIA HEAVY OIL TYPICAL	CALIFORNIA HEAVY OIL RANGES	CALIFORNIA BITUMEN TYPICAL	CALIFORNIA BITUMEN RANGES	HONDO MONTEREY TYPICAL	HONDO MONTEREY RANGES
Gravity, °API (@60°F)	13°	9-21°	7°	2-11°	17°	11-21°
Specific Gravity	0.98	1.01-0.93	1.02	1.06-0.99	0.95	0.99-0.93
Carbon, WT% (Ash Free)	87.2	Est. From	82.4	Est. From	83.2	Est. From
Hydrogen	10.6	K_w & Grav.	9.4	K_w & Grav.	10.7	K_w & Grav.
Nitrogen	0.7	0.56-0.8	1.0	0.7-1.2	0.7	0.65-0.70
Sulfur	1.2	0.23-1.6	6.2	3-8.2	5	5-5.2
Oxygen	0.3	Est. No Data	1.0	Est. No Data	0.4	Est. No Data
Metals, ppm (Ash Free)						
Iron	25	24-25	40	Estimate	294	294
Nickel	70	52-83	150	149-160	PPM	PPM
Vanadium	32	23-49	200	95-310	"Total	"Total
Sodium	---	No Data	---	No Data	Metals"	Metals"
Ash, WT%	---	No Data	---	No Data	---	No Data
Carbon Residue, WT% (Ash Free)	9	7-13	20	18-21	8	Estimate
Viscosity, cp @						
77°F	16,000	1700-25,000	$5x10^6$	$1.5x10^5$ to above 10^8	1300	Graphed
100°F	3,000	600-6500	$6x10^5$	9,000 to 10^7	446	446
210°F	75 cp	26-150	$2x10^3$	$350-3x10^6$	25	From K_w & Grav.
275°F	20	12-50	300	$80-6x10^3$	12	Graphed
Pour Point, °F	45°F	Est. From Visc	---	Too Varied To Est.	15°F	Est. From Visc.
Compound Types, WT%						
Asphaltene	6	3-6.2	10	Estimate	6	Estimate
Saturates	---	No Data	---	No Data	---	No Data
Aromatics	---	No Data	---	No Data	---	No Data
Polars	---	No Data	---	No Data	---	No Data
Distillation, Vol% @						
600°F	18	17-33	~15	18.5-23	---	---
1000°F	60	60-74	51	53	59%	59%
K Factor	11.4	11.2-11.5	11.1	10.9-11.5	11.6	11.6

reservoir is 24%, and permeability is 1,100 millidarcies.[18]

TEXAS

Heavy crude oil and tar sands are a significant resource in Texas although the in-place resource has not been consistently defined. In 1967, the U.S. Bureau of Mines estimated the volume of in-place heavy crude at 10.3 billion barrels.[29] A more recent (1977) estimate by R. L. Whiting placed the amount of in-place heavy crude oil at 30.5 billion barrels.[30] In the same study by R. L. Whiting, tar sand resources were estimated to be 140 million barrels with negligible reserves. Other estimates of the in place tar sand resources range from 2-10 billion barrels.[29] A new study (1983) by Lewin & Associates estimates Texas in place tar sand resources at 4.8 billion barrels.[13] These and other estimates are summarized in Table 11.

Over 73% of the heavy oil crude resource is located in South Texas along a 70 mile wide band paralleling the Texas Gulf Coast from the Sabine to the Rio Grande River.[30] The distribution of heavy crude and tar resources is shown in Figure 7.[29] Most of the heavy crude reservoirs are at depths of less than 2,000 feet.

Table 11

TEXAS HEAVY OIL AND BITUMEN

Source	Date	Estimated Heavy Crude Oil in Place, 10^9 Barrels
HEAVY OIL		
U.S. Bureau of Mines[29]	1967	10.3
R. L. Whiting[30]	12-31-77	30.5
TAR SANDS		
R. L. Whiting	12-31-77	0.140
W. L. Fisher[29]	-	2-10
Lewin study[13]	8-83	4.8
R. F. Meyer[11]	5-83	3.85
TOTAL HEAVY CRUDE & TAR SANDS		
W. L. Fisher[29]	6-82	12-15

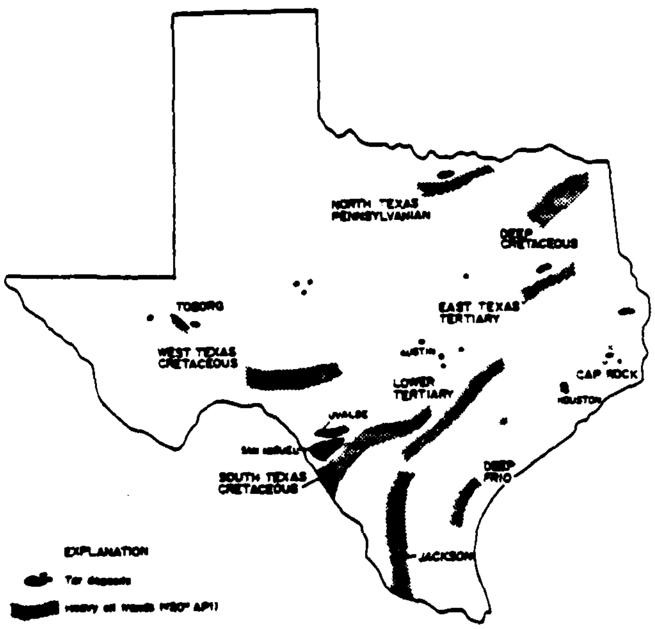


FIGURE 7.

Distribution of heavy oil and tar trends in Texas.[29]

There are four main heavy crude trends and two main tar sand districts. The four main heavy crude trends in South Texas are from the South Texas Cretaceous, the South Texas Fris, the South Texas Jackson, and the South Texas lower Tertiary. The tar deposits occur in the San Miguel Tar Belt (Upper Cretaceous) and in the Anacacho Limestone (Upper Cretaceous) of the Uvalde District.

San Miguel

The principal tar sand deposit in South Texas is the San Miguel with an estimated 3.2 billion barrels of oil in place. Conoco estimates the amount of in-place oil from two to three billion barrels of -2° API tar.[31] This tar sand deposit is at depths from 1,200 t0 2,300 feet for approximately ninety square miles. Since the early 1960's, several programs have been conducted on this resource.

The San Miguel is predominantly sandstone with irregular layers of limestone. The sand is generally very fine to fine grained, firm to hard, friable and clean except for interspersed limestone streaks. The limestone sections are generally very hard and dense with a medium to coarse crystalline section. The formation is about 20 to 80 feet thick with an average of about 50 feet. The porosity is about 20-30% with a permeability of 250 to 1,000 millidarcies. Tar saturations range from 20-60%.[31]

Uvalde

The Uvalde tar is contained in limestones of the Anacacho Formation. The formation is about 180 miles long, 25 miles wide, and 500 feet deep, and extends from southwestern Kinney County through southern Uvalde County eastward to San Antonio.

Commercial exploitation of the Anacacho asphalts began as early as 1891, with current use for paving.[29] The total in place resource is estimated to be 530 million barrels.[12]

Other Texas Trends

Significant heavy oil trends occur in lower tertiary sands in the general area of the San Marcas Arch. Heavy oil is also produced from the Trio of South Texas at depths up to 8,000 feet.[29]

The Jackson group (Eocene) is a major heavy oil trend in South Texas. Most of the trend is located in Webb and Zapata Counties.[29]

There are two heavy oil trends in West Texas. The West Texas Cretaceous trend is located in Edward and Val Verde Counties,[29] and heavy crude is produced from Toberg in Pecos County.

East Texas has an estimated in place heavy oil resource of 3 billion barrels.[29]

Material Properties

Properties of the South Texas Tars are extreme-- 10% sulfur, negative API gravities, and K factors less than 11.0 (Table 12).

KENTUCKY

Kentucky ranks fifth in the U.S. tar sand deposits with total in place resources of 3.4 billion barrels. Most of these resources are located in Edmonson and Logan counties as shown in Figure 8. There are five major tar sand deposits: Kyrock, Bee Spring, Tar Springs, Hardinsburg and Big Clifty. Commercial development is presently limited mainly to road paving materials, but these resources are becoming of greater commercial interest.

TABLE 12

SOUTH TEXAS PROPERTIES SUMMARY

San Miguel/Uvalde Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API (@60°F)	-1.0	-0.5 to 2.0
Specific Gravity	1.08	1.08 - 1.09
Carbon, WT% (Ash Free)	79.1 [80.4]	1.34
Hydrogen	8.84 [8.98]	H/C Ratio
Nitrogen	0.36 [0.36]	0.36 (3)
Sulfur	10.25 [10.25]	9.1 - 11.0
Oxygen	1.40 [0]	Est. - No Data
Metals, ppm (Ash Free)		
Iron	---	---
Nickel	24	24 - 30
Vanadium	85	85 - 100
Sodium	98	98
Ash, WT%	1.02	1.02
Carbon Residue, WT% (Ash Free)	24.5	24.5 (3)
Viscosity, cp @		
77°F	$1x10^8$	$1x10^8$
100°F	$1x10^7$	$1x10^7$
210°F	$3x10^4$	$1.35x10^4 - 3x10^4$
275°F	$2x10^3$	$2x10^3$
Pour Point, °F	175	170 - 180
Compound Types, WT%		
Asphaltene	37.4	37.4 (2)
Saturates	---	---
Aromatics	---	---
Polars	---	---
Distillation, Vol% @		
600°F	4	4
1000°F	35	34 - 36
K Factor	10.6	10.5 - 10.8

[ ] = Alternate

Kyrock, Bee Springs

Two stratigraphic units that make up the Early Pennsylvanian age are the Kyrock and Bee Spring sandstones. The largest outcrop is in northern Edmonson County. Bitumen deposits are very erratic, thicken and thin abruptly, and vary in viscosity. The deposit in Edmonson County, based upon core samples, covers 4,220 acres with a thickness of 15 to 30 feet and an overburden of 15 to 30 feet. It has been calculated that this 195 million tons of rock contain about 10 to 15 gallons per ton or 50 million barrels of in place bitumen. There is also an outcrop of Pennsylvania sandstone in Grayson County ranging from 4 to 30 feet in thickness with a bitumen content of 4 to 9 percent.[32]

During 1959 and 1960 Gulf Research and Development Company conducted a pilot test of forward combustion in a bitumen impregnated Pennsylvania sandstone in Northern Edmonson County. They concluded that fire flooding was a technically feasible method for producing oil from these tar sands.[33]

Tar Springs

The principal areas of Tar Springs sandstone are late Mississippian age and occur along the border between Hancock and Breckinridge Counties. The deposit is located at an average depth of 120 feet and is about 20 feet thick.[32]

Hardinsburg

The principal areas of Hardinsburg sandstone are of late Mississippian age. The largest deposits are in Edmonson and Warren Counties. The deposit is 10-30 feet thick at depths of 140 to 300 feet.[32]

Big Clifty

Big Clifty sandstone is the largest tar sand deposit in Kentucky. The deposit is of the Late Mississippian Age. The largest subsurface exposure is located in Logan County and covers an area of 2,553 acres. The deposit is about 15 to 35 feet thick, and is estimated to contain 37 million barrels of a bitumen.[32] The rock contains about 10 to 14.5 gallons of bitumen per ton.

Surface deposits of tar sands in Breckinridge County are about 14 feet thick and generally lie less than 20 feet deep with a bitumen content of 6 to 10 percent in the lower 7 to 8 feet. The deposits in Grayson and Hardin are about 5 to 10 feet deep and have a bitumen content of 2 to 8%.[32]

The largest subsurface occurrence of tar sands in the Big Clifty are in northern Logan, southeastern Butler, northern Warren, and central Edmonson Counties, ranging from 0 to 80 feet in thickness. Analyses of cores yield the following reservoir properties: 10-25 percent porosity, 18 to 61 percent oil saturation, and 10 to 242 millidarcies permeability.[32]

Material Properties

Average properties of Kentucky bitumen show reasonable hydrogen content with low sulfur and nitrogen (Table 13). Metals contents are intermediate (200 ppm average nickel + vanadium) while pour points are very reasonable.

NEW MEXICO

The Santa Rosa deposit is the largest known tar sand deposit in New Mexico. It is currently estimated to have reserves of 57 million barrels. Oil-impregnated rock occurs in the Santa Rosa sandstone (of the upper Triassic Age), a huge calcareous and micaceous sandstone is present as two members separated by a shale member and a conglomerate member. This formation is irregularly bedded and consists of sub-angular to subrounded, fine to medium sized quartz grains and scattered mica. The Santa Rosa deposit is contained in three separate outcrops, one smaller deposit south of the Pecos River and two larger deposits, of approximately 4,530 acres together, north of the Pecos River.[15]

Oil saturation is found in the upper and lower layers of the Santa Rosa Sandstone, but distribution is not laterally or vertically uniform. The maximum oil content is about 8 weight percent, with the average 4 1/2 to 5 percent. The Sandstone is overlain almost 50 feet by the Chinle Formation, a reddish brown to gray mudstone.

TABLE 13

KENTUCKY PROPERTIES SUMMARY

WESTERN KENTUCKY BITUMEN:

Properties	Typical	Ranges	Westken 8-ND-30B @AOI R&D
Gravity °API @ 60°F	10.4	5.7-16.6	10.4
Specific Gravity	.997	1.0313-.9554	.997
Carbon (wt%, ash free)	84.6	82.4-86.3	84.6
Hydrogen	11.0	10.7-11.2	11.2
Nitrogen	.51	.233-.82	.233
Sulfur	1.54	.7-1.74	1.66
Oxygen	1.34	--	1.34
Metals, ppm (ash-free)			
Fe - Iron	130	25-2600	335
Ni - Nickel	55	24-98	63
V - Vanadium	174	86-250	229
Na - Sodium	541	--	541
Ash, wt%	Insuf. Data	--	--
Carbon Residue wt% (ash free)	15.4	11.0-20.6	11.0
Viscosity, cp @			
77°F	200,000	260,000-44,000	--
100°F	50,000	87,000-11,000	--
210°F	400	1800-120	270
275°F	100	525-35	--
Pour Pt. °F	75°F	65-123°F	65°F
Compound Types, wt%			
Asphaltene	20.0	13.5-30.0	20.3
Saturates	27.8	27.7-28.0	28.0
Aromatics	26.4	24.1-28.6	24.1
Polars	25.8	24.1-27.6	27.6
Distillation, vol% at			
600°F	9.5	6-11	6
1000°F	48	37-60	60
K Factor	11.2	10.9-11.5	11.2

Porosity of the sand ranges 0.10-0.13 and permeability is 100-200 md. The oil gravity is 11.9° API and the viscosity 30,000 cp at 60°F. Oil recovery of 114 million barrels is believed possible[18,28] but recent re-evaluations of the resource may indicate significantly poorer resources.

Santa Rosa bitumen properties, Table I4, are particularly intriguing due to their reported low metals content (50 ppm total nickel + vanadium). Hydrogen content and K factor suggest high aromaticity, but heteroatom content is low to moderate.

ALABAMA

Mississipian age strata of the Pride Mountain Formation, Hartselle Sandstone, and Bangor Limestone in northern Alabama contain an estimated 6.5 billion barrels of asphalt and heavy oil. These petroliferous rocks outcrop in parts of Colbert, Cullman, Franklin, Lawrence and Morgan Counties. In these counties, Mississipian strata are relatively flat-lying and of fairly uniform thickness.

Pride Mountain Formation[34,35]

Heavy oil deposits occur in a sandstone within the lower part of the Pride Mountain Formation in parts of western Colbert County, in close proximity to limestones impregnated with

TABLE 14

NEW MEXICO PROPERTIES SUMMARY

Santa Rosa Bitumen:

PROPERTIES	TYPICAL	RANGES
Gravity, °API	8.5	5 - 9
Specific Gravity	1.01	1.007 - 1.037
Carbon, WT% (Ash Free)	86.0	85.6 - 86.6
Hydrogen	10.3	10.1 - 10.4
Nitrogen	0.3	0.22 - 0.31
Sulfur	2.2	1.8 - 2.34
Oxygen	1.3	1.3 - 2.4
Metals, ppm (Ash Free)		
Iron	<1	<1
Nickel	17	12 - 23
Vanadium	24	21 - 26
Sodium	11	11
Ash, WT%	----	----
Carbon Residue, WT% (Ash Free)	16	15 - 22.1
Viscosity, cp @	$3.2x10^5$	$3.2x10^5$
77°F	$4.9x10^4$	$4.9x10^4$
100°F	265	265
210°F	54	54
275°F		
Pour Point, °F	85	Estimate
Compound Types, WT%		
Asphaltene	22	19 - 21.8
Saturates	28	28.7
Aromatics	16	13.5
Polars	34	36
Distillation, Vol% @		
600°F	13	11 - 15.9
1000°F	54	54.2 - 54.5
K Factor	11.1	11.05 - 11.2

heavy oil in varying degrees. The bituminous limestone lies stratigraphically about 25 feet above the bituminous sandstone.

Bituminous sandstone of the lower Pride Mountain Formation outcrops in an area one to three miles south of the town of Cherokee in west-central Colbert County. The bituminous sandstone is generally medium to dark gray or black, very fine-grained, slightly calcareous, thinly bedded and lenticular. The impregnated interval of this sandstone ranges up to 12 feet in thickness with the average thickness 7 to 8 feet. The degree of heavy oil saturation ranges from 4 1/2 to 10 1/2 weight percent with the overburden thickness 0 to 350 feet.

The largest and most significant occurrence of bituminous limestone in North Alabama is located in west-central Colbert County and just south of the town of Margerum. These limestone beds are commonly about 25 feet thick; the part impregnated with heavy oil is variable in thickness, in some cases reaching a thickness of 20 feet. The bitumen content of these rocks ranges from 3.2 to 7.5 weight percent.

Hartselle Sandstone[34,35]

The Hartselle Sandstone is the most extensive and richest asphaltic rock of the Alabama deposits. It is part of a transitional sequence from terrigenous facies in the

southwest to a central carbonate facies. The Hartselle extends northeastward and southwestward, consisting of numerous subparallel linear thicknesses that run northwest to southeast. These lenticular formations range in size from 10 to 35 miles long, 1 to 8 miles wide and up to 150 feet thick.

Lithofacies affect oil saturations of the Hartselle, with higher saturations occurring in the "clean" sandstone. The "richer" deposits of the Hartselle Sandstone are located in the area of southeast Colbert County and west-central Lawrence County where saturations range up to 9 percent by weight and 68 percent of pore space. Thicknesses of the outcrop range up to 20 feet. Estimates of the total reserves for the Hartselle in both the outcrop and subsurface range up to 3.5 billion barrels. These deposits are summarized in Table 15.

Tar sand outcrops of the Hartselle Sandstone are characterized by rolling terrain, being deeply weathered and with few natural exposures of bedrock. Hartselle Sandstone exposures are most often found to be tightly cemented, fine grained sandstones with no trace of hydrocarbons.

The degree of asphalt impregnation varies with color, which ranges from gray to black. On freshly broken surfaces the richer rock deposits are black and may even drip with oil as well as emit a strong odor of heavy crude.

Table 15 Hartselle Sandstone Deposits[34]

Name	Thickness	Overburden	Bitumen Content
Hartselle City	0-8 feet	0-40 feet	5-6 wt.%
Flint	0-10 feet	0-40 feet	3-1/2-7 wt.%
Caddo	0-18 feet	0-50 feet	4 wt.%
Wolf Springs	0-10 feet	0-30 feet	0-9-1/2 wt.%
Shine's Springs	0-16 feet	0-70 feet	0-9-1/2 wt.%
Littleville	0-16 feet	0-220 feet	0-6-1/2 wt.%
Frankfort	75-90 feet	0 (at the outcrop)	----

OKLAHOMA

The state of Oklahoma has about 600-1200 million barrels of heavy oil and/or bitumen in place and reserves of 60 million barrels.[12] About 20% of Oklahoma's heavy oil and oil sand are in south Central Oklahoma in the counties of Carter and Murray. These counties have tar, oil and asphalt either occurring at the surface or being produced at depths of 500 feet or less. The bitumen occurs in several Ordovician formations and in a Pennsylvanian unit.

Most of the bitumen is found in the Oil Creek Formation. The entire area is structurally complex and a relationship between the tar sands and faulting has been proposed.[36] The Oil Creek Formation consists of an upper sequence of interbedded limestone and shale and a basal sandstone that consists of a very pure silica sand. Bitumen content ranges from 4 to 18 percent.

The geology of Murray County and Carter County is complex. All of the occurrences in Carter County are in sandstone of Pennsylvanian Age. Some of the bitumen - impregnated sandstones can be traced on the surface for miles. Carter County contains several inactive quarries and outcrops that have been prospected or sampled for bitumen; two major quarries have bitumen concentrations of 8 to 17 percent. Other outcrops sampled have up to 12 percent bitumen.

LOUISIANA

Louisiana contains a reservoir in the Macottock sand which is massive, with poorly consolidated to unconsolidated sand containing streaks or sandy shale and fossiliferous limestone. Its measurable resource properties are a porosity of 0.34, permeability of 695 md, and oil saturation of 0.74. The reservoir temperature is 75°F.

KANSAS

Kansas has been estimated to have 20 million tons of heavy oil containing 10% mineral matter. Evaluation of the heavy oil and tar sands in Bourbon, Crawford and Cherkee counties in Kansas have indicated a resource base of 200 million barrels of oil in-place.

Two fields in Allen County are the Iola Field, which has an oil saturation of 65% and 96 million barrels of oil in-place, and the Moran field, which has an oil saturation of 76% and 95 million barrels of oil in place.

MISSOURI[37]

Missouri has a reported 1.4 to 1.9 billion barrels of oil in place, none of which is considered a reserve. In the western part of Missouri, tar sand resources are concentrated in the strata of the Pennsylvania Age. The stratigraphically lowest oil-impregnated rocks occur in the Warner unit, a sequence of sandy shale, sandstone and coal beds. Tar sand in the Upper Warner is widespread but is also discontinuous.

The Tri-State area (southeastern Kansas, southwestern Missouri and northeastern Oklahoma) contains heavy oil deposits with gravities ranging from 8° to 25° API. Oils in the lower range are very viscous to semi-solid and occur most frequently in rocks of the Cherokee Group of the Middle Pennsylvania Age. The Cherokee is a sequence of alternating shales and sandstones with thin coal and limestone beds. This sequence varies in thickness, from zero meters at the outcrop to 160 or 200 meters in Kansas and Oklahoma. It dips westward at 4 to 6 meters per kilometer. In Missouri heavy oil sands are present from exposure at the surface to depths

of less than 30 meters. Deposits in western Missouri and eastern Kansas range from 30 meters to 150 meters. The main reservoirs are the Bluejacket sandstone and the Warner sandstone.

The Warner and Bluejacket sandstones are products of a prograding fluvial dominated delta system. The Warner sandstone corresponds to widespread distributary subdeltas with frequent connections between sand bodies. The Bluejacket sandstone corresponds to distributary channel sands that are embedded in low delta plain sediments.

The Warner crude is heavier (10°-14° API) than the Bluejacket crude (19° API). The Warner crude is devoid of light ends. The compositions of the crudes show a depletion of saturates between the Bluejacket and Warner crudes. There appears to be a significant increase in saturates and aromatics in the least porous and least permeable reservoir sample.

The newest estimates for this area are 1490 million barrels of oil in place with reserves of 150 million barrels.[12]

III. REFINING OF TAR SANDS BITUMEN AND HEAVY OIL

Bitumen and heavy oils are quite similar to conventional atmospheric and/or vacuum residues. In fact, the probable origin of many of these materials was as conventional oil, with lighter components lost during migration and/or due to the permeability of the formation. As a result, some techniques developed for processing conventional petroleum residues may be applicable to these materials.

Table 16 summarizes the problems which are encountered by the refiner when processing tar sands bitumen and/or heavy oil. Assuming adequate in-place boiling range conversion capabilities, the critical upgrading factor will be the asphaltene content. These asphaltenes primarily contain the metal and carbon contaminants which prevent the use of conventional refining routes. Other properties, particularly solids, water, salts, etc., not amenable to normal separations, make it unlikely that conventional routes can be mechanically successful when charged with these materials. Finally, end fuel uses are generally dictated by hydrogen content; either external hydrogen addition or some method which maximizes use of native hydrogen must be practiced. Since external hydrogen addition is generally expensive, this route should be limited as much as possible.

These considerations lead to definition of the following

TABLE 16.

POTENTIAL CHARACTERISTICS OF OIL SANDS AND HEAVY CRUDES WHICH COULD CAUSE PROBLEMS DURING REFINING

- HIGH METALS LEVELS
- HIGH WATER CONTENT
- HIGH PARTICULATE CONTENTS
- THE MATERIAL IS NOT AMENABLE TO CONVENTIONAL DESALTING
- HIGH HETEROATOM CONTENT, PARTICULARLY SULFUR
- HIGH CONRADSON CARBON CONTENT
- HIGH ASPHALTENE CONTENT
- HIGH LEVELS OF RESIDUAL (BOILING GREATER THAN 1000 F) COMPONENTS
- LOW YIELDS OF NAPHTHA AND DISTILLATE MATERIALS
- LOW API GRAVITY
- LOW HYDROGEN CONTENT

criteria for a preferred process:

- Capable of handling high (500ppm) metals levels.
- Tolerant of water, solids, and other contaminants in the feed.
- Capable of removing, converting or utilizing high carbon contents.
- Able to maximize use of native hydrogen content.
- Allow provisions to handle high levels of sulfur.
- Control boiling range conversion to optimize product slates.

Available commercial refining technology and some experimenal processes were evaluated with these criteria in mind. Combination of these and other processes is obviously a further possibility, for instance the conventional route of delayed coking followed by fixed bed hydrogenation. Fixed bed processes are not included in this evaluation of primary upgrading routes, however, since commercial run lengths for these processes are very doubtful without first-stage upgrading.

Overall analysis of these options leads to the following process conclusions; optimum selection will probably be user, site, and material specific.

- CONVENTIONAL PROCESSING - Delayed and fluid coking followed by fixed-bed hydrogenation are presently in commercial practice in Canada. These routes offer the most certain, proven capability to upgrade bitumen. They suffer, however, from relatively non-selective

yield structures, high yields of coke, and disposal problems involved with the high sulfur, high metals coke.

- OPTIMUM PRODUCT COST: In cases where open product slates are allowed, and where high volumes of gasoline can be sold, fluid cracking processes with properly designed catalysts are probably preferred. These processes can be selective to highest valued products, are very tolerant to feed contaminants and produce no net byproduct streams for disposal except for metals-containing catalyst. Fluid cracking offers the further advantage of directly producing high quality gasoline with a relatively low hydrogen content, thus limiting further processing required while maximizing use of the native hydrogen content of the feed. These processes are presently being commercially demonstrated on heavy feed by Ashland Oil and others.

- MAXIMUM DISTILLATES/TURBINE FUELS: For those cases where maximum total volume is required, particularly of middle distillate type fuels, the hydrogen addition routes are generally favored. While cost of these processes can be high, they tend to maximize utilization of feedstock carbon content, allowing net volumetric recoveries up to or exceeding 100 percent of feed. The ebullating bed technologies are favored, since they offer reaction selectivity at relatively high rates while being tolerant to water, particulates, etc., in the feed. Multi-stage operations are probably optimum to minimize catalyst costs. Significant experimental work has been performed in this area, and commercial experience is available for conventional feedstocks.

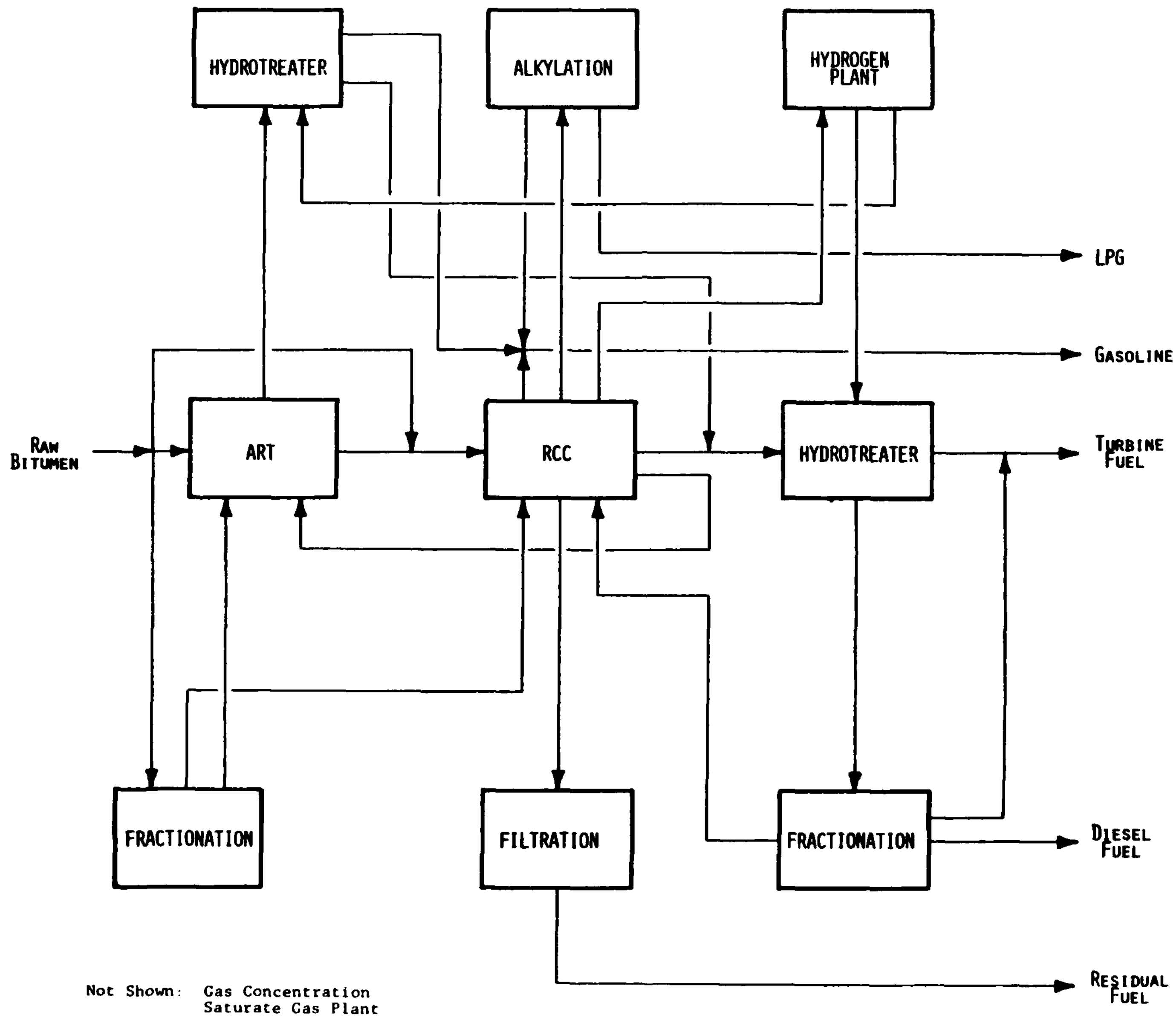
Overall, these directions indicate that the fluid cracking route should be investigated in view of cost optimum product requirements. Direct production of total transportation fuels from these materials at the lowest possible cost would be expected to free conventional feedstocks for turbine fuel uses at the lowest total system cost.

IV. PROCESS DESCRIPTION

The process selected for primary evaluation is Ashland's RCC^{sm} process technology. This process has been developed based on laboratory, demonstration, and commercial scale equipment. A 40,000 BPD RCC unit has been successfully operated at Catlettsburg, Kentucky, since April, 1983. A companion ART unit is also in use at Catlettsburg. Details of each of these processes, and recent commercial experience, have been published elsewhere[38-41]. Adaptations of these technologies are to be developed under this program to allow processing of bitumen stocks.

The overall process flow sheet for this study is shown in Figure 9. Changes in this flow sheet occur based on yields and/or material requirements due to specific feedstock characteristics. The following description defines the Phase I analysis concept; future generations of this concept are probable as laboratory data are developed.

Raw bitumen feed to the complex is admixed with a refractory RCC product for dispersion and viscosity control; heavy oil (>15°API) is not diluted. This material is charged to the ART unit for metals removal, with an option to bypass some or all of this material to the RCC if desired. ART products are separated into fuel gas, C_3+C_4, naphtha, distillate, and bottoms in the associated main column and gas concentration unit.



Not Shown: Gas Concentration
Saturate Gas Plant
Sulfur Plant
Offsites and Tankage

FIGURE 9 OVERALL PROCESS SCHEMATIC

The RCC Unit may be fed by raw feed, ART distillate, ART bottoms and/or recycle hydrogenated components ranging up to 900°F. The module contains gas separation plus flue gas treating, and produces sour fuel gas, mixed $C_3 + C_4$, C_5-430 (or 330°F) gasoline, 330 or 430°F-630°F cycle oil and 630°F+ resid. Fractionation options allow cuts as deep as 900°F for recycle hydrogenation. Gasoline end point may be varied to control sulfur content of gasolines from high sulfur feedstocks. RCC gasoline and bottoms may be directed to finished product blending as needed.

Products for blending with streams other than gasoline, and for recycle, are hydrotreated. All raw ART naphtha is olefin saturated, then blended to gasoline or further hydrogenated for turbine fuel. Components for turbine or diesel fuels are all hydrogenated at relatively high severity for significant hydrogen input as required by product specifications.

Mixed C_3/C_4 streams are routed to HF alkylation with the ART product processed first through a small propadiene/butadiene saturation section.

Hydrogen is provided either by fuel gas steam reforming or by partial oxidation of residual material. Plant fuel is provided by the remaining fuel gas or resid. For hydrogen

deficient cases, all C_3 and C_4 components may also be burned as fuel or utilized in the steam reformer.

The sulfur plant module includes fuel gas amine treatment, Claus-type sulfur recovery and tail gas cleanup.

Major design parameters, operating ranges, and construction materials are summarized in Appendix A.

V. BASES, ASSUMPTIONS, AND CASE DEFINITIONS

The major Phase I objective was the determination of the relative economic incentive for processing tar sand bitumen and/or heavy oil materials via the selected process. A range of feedstock qualities was selected which brackets available material qualities. A process model was developed for these feedstocks, pertinent bases and assumptions were defined in conjunction with contract monitoring personnel, and these data were utilized to derive an LP model for individual evaluation of each case.

Feedstocks

Four feedstock types were selected for evaluation:

Type	Source	Characteristics
High Nitrogen	Uinta Basin, Utah-Sunnyside	Nitrogen content about 1% or more; low sulfur, high (>11%) hydrogen, low concarbon; may have some shale kerogen.
Moderate Sulfur	Kentucky, California	Sulfur 1-2 percent, hydrogen high (>11%), moderate concarbon.
High Sulfur	Southeast Utah-Tar Sand Triangle	Sulfur 4-5 percent, hydrogen 10%, nitrogen 0.5%, high concarbon.
High Sulfur Heavy Oil	California	Sulfur 5-6%, hydrogen about 11 percent, intermediate metals, moderate carbon content.

These materials were selected in an attempt to bracket probable available qualities of feedstocks.

Design basis properties used are presented in Table 17. These properties are based primarily on literature information and may not be characteristic of specific materials; actual analytical evaluation is scheduled for Phase II. A wide spread of gravity and hydrogen, metal, and heteroatom content is demonstrated by these materials.

Assumption and Bases

For the most part, assumptions and bases used in these studies were defined in conjunction with Air Force personnel. Details are shown in Tables 18 through 21. Initial values were modified as required to provide realistic process solutions.

Capital costs were estimated from information obtained by two methods. RCC/ART capital costs were based on construction of a 55,000 BPD ART unit and a 40,000 BPD RCC unit at Catlettsburg, Kentucky. Total base costs for this complex were approximately 300MM dollars, including process units, main columns, gas concentration, limestone boilers, baghouses and major supply systems. For the purpose of this analysis, this capital cost was assumed to be a grass-roots cost. This assumption results in under-estimation of tankage costs, plus

TABLE 17

DESIGN BASIS MATERIAL PROPERTIES

Item Location	Sunnyside Utah	Tar Sand Triangle Utah	Western Kentucky	California
°API	9.3	11.1	10.4	17.4
Elemental Analysis, wt% (ash-free)				
Carbon	86.3	84.0	85.5	82.4
Hydrogen	11.1	10.1	11.3	10.7
Nitrogen	0.9	0.4	0.2	0.7
Sulfur	0.5	4.4	1.7	5.2
Oxygen	1.2	1.1	1.3	1.0
Metal, ppm (ash-free)				
Iron	200	-	335	
Nickel	85	53	63	294
Vanadium	20	108	229	
Sodium	-	-	-	
Carbon Residue, wt%	16	22	11	7
K Factor	11.3	11.2	11.2	11.6
Pour Point, °F	140	-	65	
Distillation, vol% at				
600°F	5	12	6	-
1000°F	36	40	60	60
Component Type, wt% (vol%)				
Asphaltene	20	26	20	-
Saturates	40	26	28	-
Aromatics	15	32	24	-
Polars	25	16	28	-

TABLE 18

INVESTMENT AND RETURN BASES

1. CAPITAL INVESTMENT

REFINERY CAPACITY: 30,000 BBLS/DAY FOR TAR SANDS
50,000 BBLS/DAY FOR HEAVY OIL

COST BASE: CE INDEX = 319

PLANT OFF-SITES: 45% OF PLANT ON-SITES

FINANCING: 100% EQUITY
THREE-YEAR CONSTRUCTION PERIOD:
25% FIRST YEAR
50% SECOND YEAR
25% THIRD YEAR

INVESTMENT TAX CREDIT: 10% FIRST YEAR

2. CAPITAL RETURN

DISCOUNTED CASH FLOW RATE: 15%

PLANT SALVAGE VALUE: ZERO

PLANT DEPRECIATION: 5 YEAR ACCELERATED COST RECOVERY SYSTEM

TABLE 19

WORKING CAPITAL

CRUDE INVENTORY:	21 Days Storage Capacity/14 Days Inventory
PRODUCT INVENTORY:	14 Days Storage Capacity/7 Days Inventory
CRUDE MATERIAL:	$25.00/Bbl Tar Sands Bitumen or Heavy Oil
PRODUCT PRICE:	All Liquid Military Transportation Fuels Valued at a Price which Provides a 15% DCF Rate of Return (Gasoline, JP-4,JP-8, and DF-2). o Fuel Gas $23.00/FOE Bbl o Propane $21.00/Bbl o Isobutane $31.00/Bbl o Normal Butane $29.00/Bbl o Sulfur $110/Long Ton o Residual Fuel $25.00/Bbl
DEBT FINANCING:	15%, Including the Cost of Initial Catalyst

TABLE 20

OPERATING BASES

PLANT LIFE: 16 YEARS

PLANT OPERATING FACTOR: 50% OF CAPACITY, FIRST YEAR
90% OF CAPACITY, THEREAFTER

STARTUP COSTS: 10% OF ERECTED PLANT COSTS

OPERATING COST BASES

PROCESS HEAT: $25.00/BBL FOE

COOLING WATER: 7¢/1000 GALLONS

BOILER FEED WATER: 40¢/1000 POUNDS

ELECTRICAL POWER: 5¢/KWHR

OPERATING LABOR: $15.00/MAN HOUR

SUPERVISION: 25% OF DIRECT LABOR

OVERHEAD: 100% OF DIRECT LABOR

TAXES: FEDERAL AND STATE COMBINED AT 50%

MAINTENANCE, TAXES, AND INSURANCE: 4.5% OF FIXED INVESTMENT

TABLE 21.

FEEDSTOCK VALUATION
1983 PRODUCT PRICES

PRODUCT VALUE BASIS

	$/BBL
LPG	21.00
Regular Gasoline	37.20
Unleaded Gasoline	38.43
JP-4	38.73
JP-8	38.73

probable underestimates in wastewater, supply, and disposal areas. Overall, however, this cost should be valid for comparisons of selected cases in this report.

Capital costs for other plant sections were obtained from literature values. These values were updated to a Chemical Engineering cost index of 319. Off-site facilities were costed at 45% of plant on-sites.

Plant sizes were selected to provide a total of 50,000 BPD to the demetallization section. Total bitumen input to the plant was limited to 30,000 BPD due to the requirement of a diluent for proper feed distribution and fluidization. Plant sizes were selected to be near-optimum scale for single plant RCC and/or ART modules. Larger sizes would increase the efficiency of the plant upgrading section, but would require multiple parallel demetallization units.

Smaller size modules were also briefly examined, particularly for the case of on-site upgrading, as might be feasible for remote Utah deposits. However, the economy of scale was such that a 7500 BPD unit producing only a syncrude resulted in a processing cost of about $25/barrel. It is doubtful that any plant of this size could be built, unless it was combined with production steam requirements or otherwise integrated with a production facility. This scale is not amenable to

production of finished products. Larger scale operations could be economical if the producing fields were unitized.

Operating costs and feedstock values were estimated to be comparable to mid-1983 levels. Product value calculations were based on equal-value transportation fuels at 15% DCF rate of return. Alternative cases were also calculated based on feedstock values, using mid-1983 relative product values.

Modeling and Case Studies

All of the information described previously was used to develop an overall refinery LP model for these materials. The model provided a complete capability for processing and blending materials to conventional specification fuels, such that all required constraints and product requirements were met. Only conventional, finished materials were allowed, while inputs were limited to the bitumen or heavy oil of interest, isobutane, normal butane, and electrical power.

Primary case studies were performed for the Westken and the Hondo materials, with limited studies for the Sunnyside and Tar Sand Triangle feeds. Cases were developed for base (optimum) solutions, variations in required turbine fuel production levels above the base, and for feedstock

valuations based on relative 1983 product values. In some cases, multiple options were required to obtain feasible solutions.

Modifications were made during the case studies to allow hydrogen generation by partial oxidation instead of steam reforming. This was required to solve specification problems with the high-sulfur feedstocks.

Plant fuel was provided by fuel gas or residual fuel, depending on the hydrogen production method, fuels available, and/or sulfur level of the residual fuel produced. Plant fuel sulfur specifications were set at 2 percent, while the sulfur level of saleable resid was allowed to rise to 3 percent.

Model solutions should be valid within the scope of the study and the validity of the input data. In many cases, value estimations were required which were based on conventional materials. Actual Phase II data are needed to confirm these estimates.

VI. RESULTS

A total of 26 evaluative cases were prepared, with major results presented in this report. These results are described below by feedstock, followed by a feedstock comparison. For each material, a base case was evaluated which represented a predicted optimum solution for the constraints given. Change cases were then developed for variations in turbine fuel production rates, product value differentials, etc.

Hondo (California Heavy Oil)

The Hondo oil is a relatively high API gravity, high sulfur material with significant hydrogen content. Due to the sulfur content of the material, partial oxidation of residual fuel was provided for hydrogen production in the base case; plant fuel was fuel gas. Later information indicated that the product properties and responses estimated for this material may change due to unanticipated higher quantities of light (naphtha) components.

Table 22 and Figure 10 summarize base case results for this material. A capital cost of $509MM produces roughly 55M BPD of prime products from 60M BPD of total heavy oil plus butane feedstocks. Of particular interest, no residual fuel is produced from this material.

TABLE 22. HONDO RESULTS

HONDO OIL
BASE CASE

INVESTMENT DATA

FIXED CAPITAL, MM$	509
WORKING CAPITAL, MM$	40

INVESTMENT DISTRIBUTION, % OF TOTAL:

ART	20.5
RCC	19.5
ALKYLATION	3.3
HYDROGENATION	11.6
HYDROGEN PLANT	7.9
SULFUR RECOVERY	2.2
OFFSITES	35.0

HONDO OIL

BASE CASE

MATERIAL FLOWS

FEEDSTOCKS:	BPCD	% OF TOTAL INPUT
CRUDE	49,948	83.1
ISOBUTANE	7,010	11.7
NORMAL BUTANE	3,152	5.2
TOTAL IN	60,110	100.0
PRODUCTS:		
LPG	1,872	3.1
GASOLINE	37,364	62.2
JP-4	5,248	8.7
DIESEL, DF-2	10,323	17.2
TOTAL OUT	54,807	91.2
PRIME PRODUCT YIELD, VOL.%		88
ESTIMATED THERMAL EFF. NET %		83

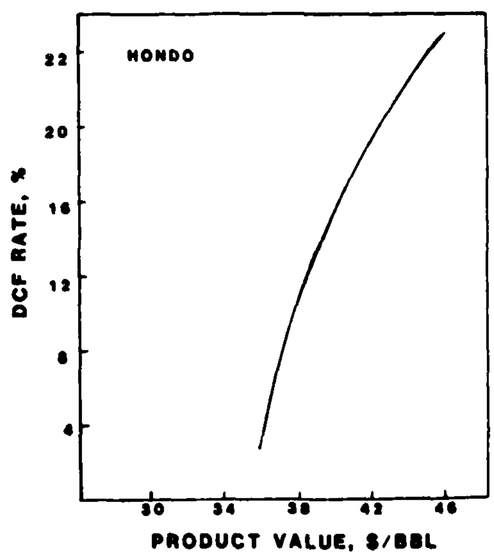
HONDO OIL

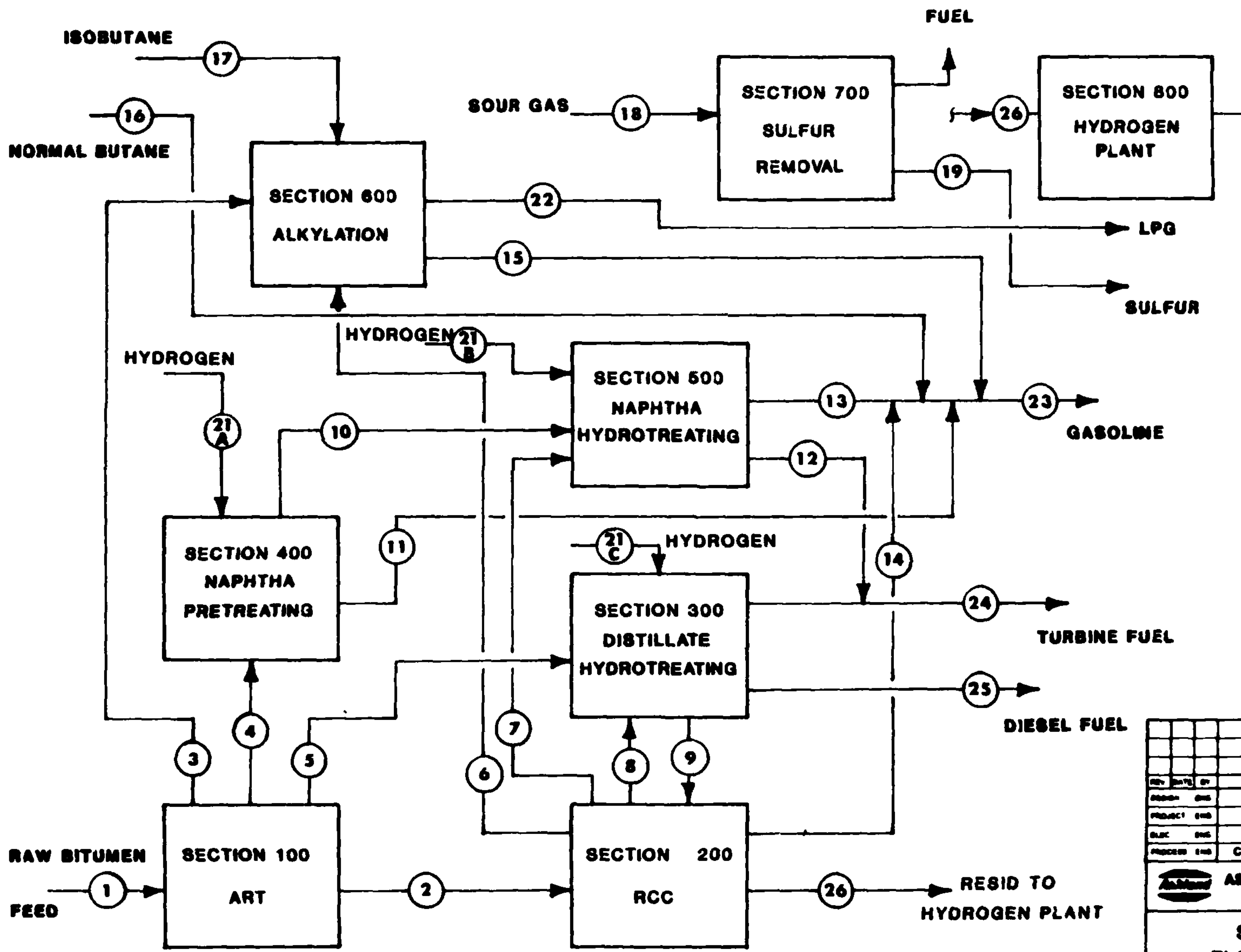
BASE CASE

PRIME PRODUCT COST DISTRIBUTION
52,935 BPCD PRIME PRODUCTS

COST ELEMENT	$/BBL PRIME PRODUCTS	% OF COST
START-UP	0.17	0.4
WORKING CAPITAL	0.32	0.8
BYPRODUCTS	(1.23)	(3.2)
FIXED COSTS	1.62	4.0
INCOME TAXES	2.74	6.7
UTILITIES	3.13	7.7
CAPITAL	4.72	11.5
RAW MATERIALS	29.43	72.0
TOTAL	40.90	

( ) Denotes Credit





MAJOR PROCESS FLOWS	
Stream No.	Flow BPSD
1	50,000
2	33,650
3	2,747
4	7,151
6	1,670
7	6,547
8	0,375
14	10,708
15	11,434
16	3,182
17	7,010
19	282 TPSD
21	45 $MMSCFD
22	1,872
23	37,364
24	5,248
25	10,323
26	2,583

C. A. JOHNSON

ASHLAND PETROLEUM CO.

SIMPLIFIED
FLOW DIAGRAM
BITUMEN REFINING

SCALE NTS
DATE 3/12/84

FIGURE 10

CASE 0 : BASE CASE HONDO HEAVY OIL WITH PARTIAL OXIDATION

The primary product cost element is raw material, followed by capital and utilities. Estimated product costs are about \$40.90/bbl (97¢ gallon).

Increased turbine fuel yields are attainable for this material, Table 23, primarily by increasing hydrogen input to the products. Generation of this additional hydrogen reduces total yield slightly while requiring significant additional capital investment. The net effect of increasing turbine fuel yield by about 17,000 BPD was to increase the turbine fuel cost by about \$3.30/bbl (8¢/gallon).

Finally, calculation of a net feedstock value at 1983 product prices resulted in a similar total product yield, with a shift in product distribution (Table 24). Net value of this material was estimated to be \$22/barrel, compared to conventional 1983 benchmark crude values of about \$29-30/barrel.

Westken

The Westken oil is a low API gravity, low sulfur material with a high hydrogen content. Metals levels for this material are similar to the Hondo stock. Steam reforming of fuel gas was used for hydrogen production, and residual oil for plant fuel.

Base case (Table 25 and Figure 11) results show about 34M BPD

TABLE 23

HONDO OIL

COST OF INCREMENTAL JP-4 PRODUCTION

	Base Case	Increment #1	Increment #2
FEEDSTOCKS, BPCD:			
Crude	49,948	49,998	49,998
Isobutane	7,010	6,919	6,990
Normal Butane	3,152	1,792	1,811
	60,110	58,709	58,799
PRODUCTS, BPCD:			
LPG	1,872	2,346	2,335
Gasoline	37,364	28,015	27,986
JP-4	5,248	22,725	22,793
DF-2	10,323	-0-	-0-
	54,807	53,086	53,114
CAPITAL INVESTMENT, MM$	509	541	541
PRODUCT COST, $/Bbl	40.90	42.40	42.50
TURBINE FUEL COST, $/Bbl*	40.90	44.25	44.50

* Assuming other prime products are constant

TABLE 24

HONDO OIL

FEEDSTOCK VALUATION - 1983 PRODUCT PRICES

FEEDSTOCKS, BPCD	
Crude	49,998
Isobutane	6,939
Normal Butane	3,250
TOTAL	60,187
PRODUCTS, BPCD	
LPG	1,714
Regular Gasoline	10,146
Unleaded Gasoline	27,780
JP-4	105
JP-8	14,824
TOTAL	54,569
CAPITAL INVESTMENT, MM$	504
FEEDSTOCK VALUE $/BBL	22.00

of products from 37M BPD of bitumen and butane, with about 2M BPD of LPG and residual fuel produced. The major cost elements were again raw material and capital, with capital being a slightly higher proportion of total cost than for the Hondo. Base case product costs were $43.20/bbl ($1.03/gallon). Incremental turbine fuel production of 14M BPD was attained at a cost of $44.20 ($1.05/gallon), Table 26. Feedstock valuation was defined to be about $19/barrel (Table 27).

Sunnyside

The Sunnyside oil is a low API gravity, low sulfur and low metals material with a relatively high carbon residue. Steam reforming was used for hydrogen production.

Plant costs were very similar to those for the Westken case, producing 32M BPD of products from 36 M BPD of feeds (Table 28). Catalyst/sorbent costs were slightly lower than for the Westken due to the relatively low metals content of this feed. Product cost, $43.60/bbl ($1.04/gallon), was slightly higher due to lower net yields, probably because of the high carbon content. Surprisingly, however, a higher feedstock value ($20/BBL) was found for this material than for the Westken feed (Table 29). Figure 11 summarizes the overall flow diagram.

Tar Sand Triangle

The Tar Sand Triangle bitumen is a low API gravity, low

TABLE 25. WESTKEN RESULTS

WESTKEN OIL

BASE CASE

MATERIAL FLOWS

FEEDSTOCKS:	BPCD	% OF TOTAL INPUT
BITUMEN	29,999	81.6
ISOBUTANE	4,634	12.6
NORMAL BUTANE	2,144	5.8
TOTAL IN	36,777	100.0
PRODUCTS:		
LPG	1,240	3.4
GASOLINE	25,979	70.6
JP-4	2,524	6.9
DIESEL, DF-2	3,461	9.4
RESIDUAL FUEL	630	1.7
TOTAL OUT	33,834	92.0
PRIME PRODUCT YIELD, VOL.%		87
ESTIMATED THERMAL EFF. NET %		82

WESTKEN OIL
BASE CASE

INVESTMENT DATA

FIXED CAPITAL, MM$	360
WORKING CAPITAL, MM$	25

INVESTMENT DISTRIBUTION, % OF TOTAL:

ART	27.8
RCC	23.4
ALKYLATION	3.6
HYDROGENATION	9.5
HYDROGEN PLANT	3.5
SULFUR RECOVERY	1.1
OFFSITES	31.0

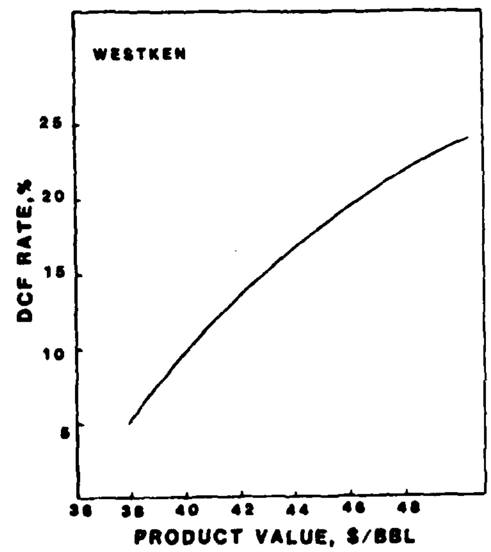
WESTKEN OIL

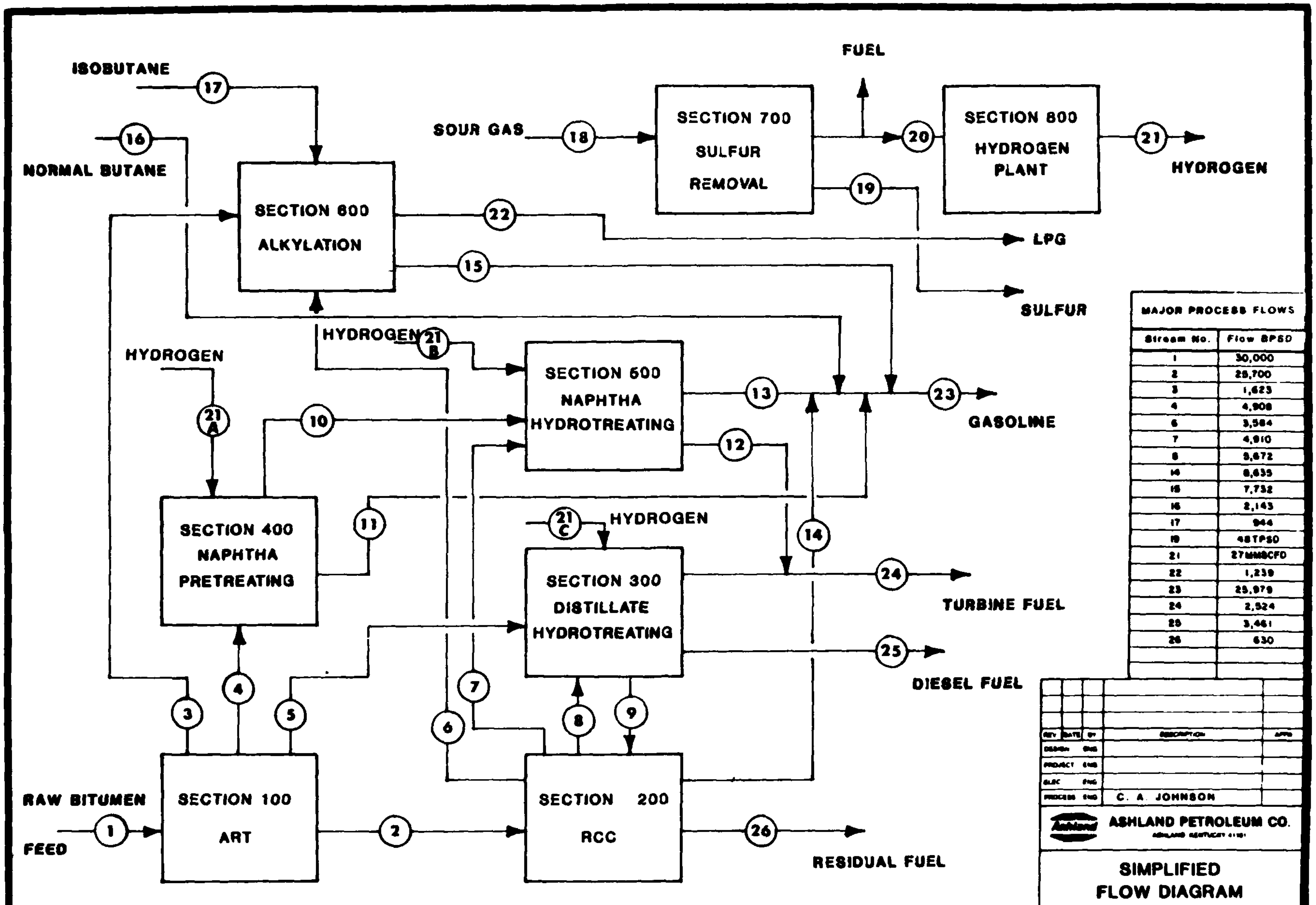
BASE CASE

PRIME PRODUCT COST DISTRIBUTION
31,964 BPCD PRIME PRODUCTS

COST ELEMENT	$/BBL PRIME PRODUCTS	% OF COST
START-UP	0.20	0.5
WORKING CAPITAL	0.34	0.8
BYPRODUCTS	(1.46)	(3.4)
FIXED COSTS	2.04	4.7
INCOME TAXES	3.22	7.5
UTILITIES	3.31	7.7
CAPITAL	5.62	13.0
RAW MATERIALS	29.90	69.3
TOTAL	43.17	

( ) Denotes Credit





MAJOR PROCESS FLOWS	
Stream No.	Flow BPSD
1	30,000
2	28,700
3	1,623
4	4,908
6	3,584
7	4,910
8	9,672
14	8,635
15	7,732
16	2,143
17	944
19	48TPSD
21	27MMSCFD
22	1,239
23	25,979
24	2,524
25	3,461
26	630

FIGURE 11

CASE A : BASE CASE WESTKEN BITUMEN WITH STEAM REFORMING

TABLE 26

WESTKEN OIL

COST OF INCREMENTAL JP-4 PRODUCTION

	Base Case	Increment #1	Increment #2
FEEDSTOCKS, BPCD:			
Bitumen	29,999	29,999	29,999
Isobutane	4,634	4,267	4,267
Normal Butane	2,144	1,008	1,459
	36,777	35,274	35,725
PRODUCTS, BPCD:			
LPG	1,240	1,004	361
Gasoline	25,979	14,894	15,019
JP-4	2,524	16,682	16,803
DF-2	3,461	-0-	-0-
Residual Fuel	630	-0-	-0-
	33,882	32,580	32,618
CAPITAL INVESTMENT, MM$	361	378	379
PRODUCT COST, $/Bbl	43.17	43.70	43.90
TURBINE FUEL COST, $/Bbl*	43.17	44.17	43.90

* Assuming other prime products are constant

TABLE 27

WESTKEN OIL

FEEDSTOCK VALUATION - 1983 PRODUCT PRICES

FEEDSTOCKS, BPCD	
Bitumen	29,999
IC_4	4,247
NC_4	2,017
TOTAL	36,263
PRODUCTS, BPCD	
LPG	1,082
Regular Gasoline	1,229
Unleaded Gasoline	22,636
JP-4	663
JP-8	6,928
TOTAL	32,538
CAPITAL INVESTMENT, MM$	385
FEEDSTOCK VALUE, $/BBL	19.10

AD-A151 319 AVIATION TURBINE FUELS FROM TAR SANDS BITUMEN AND HEAVY OILS PART 1 PROCESS ANALYSIS(U) ASHLAND PETROLEUM CO KY H F MOORE ET AL. SEP 84 AFWAL-TR-84-2070-PT-1 2/2

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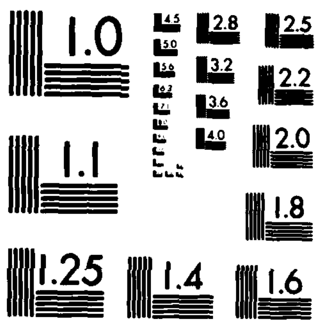


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 28. SUNNYSIDE RESULTS

SUNNYSIDE OIL
BASE CASE

INVESTMENT DATA

FIXED CAPITAL, MM$	365
WORKING CAPITAL, MM$	25

INVESTMENT DISTRIBUTION, % OF TOTAL:

ART	29.0
RCC	23.3
ALKYLATION	3.3
HYDROGENATION	9.4
HYDROGEN PLANT	3.5
SULFUR RECOVERY	0.5
OFFSITES	31.0

SUNNYSIDE OIL

BASE CASE

MATERIAL FLOWS

FEEDSTOCKS:	BPCD	% OF TOTAL INPUT
BITUMEN	29,970	83.6
ISOBUTANE	3,871	10.8
NORMAL BUTANE	2,017	5.6
TOTAL IN	35,858	100.0
PRODUCTS:		
LPG	1,117	3.1
GASOLINE	24,877	69.4
JP-4	2,557	7.1
DIESEL, DF-2	3,108	8.7
RESIDUAL FUEL	433	1.2
TOTAL OUT	32,092	89.5
PRIME PRODUCT YIELD, VOL.%		85
ESTIMATED THERMAL EFF. NET %		78

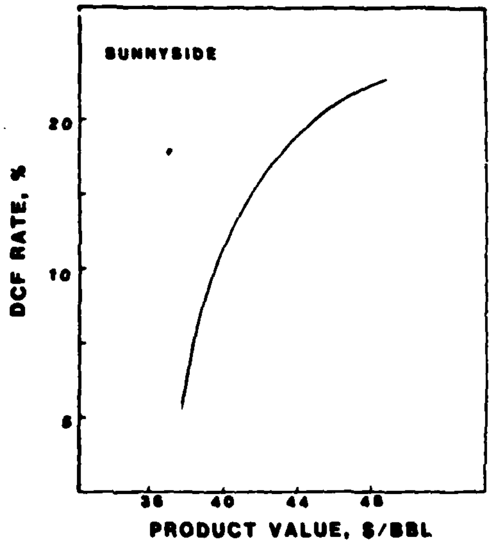
SUNNYSIDE OIL

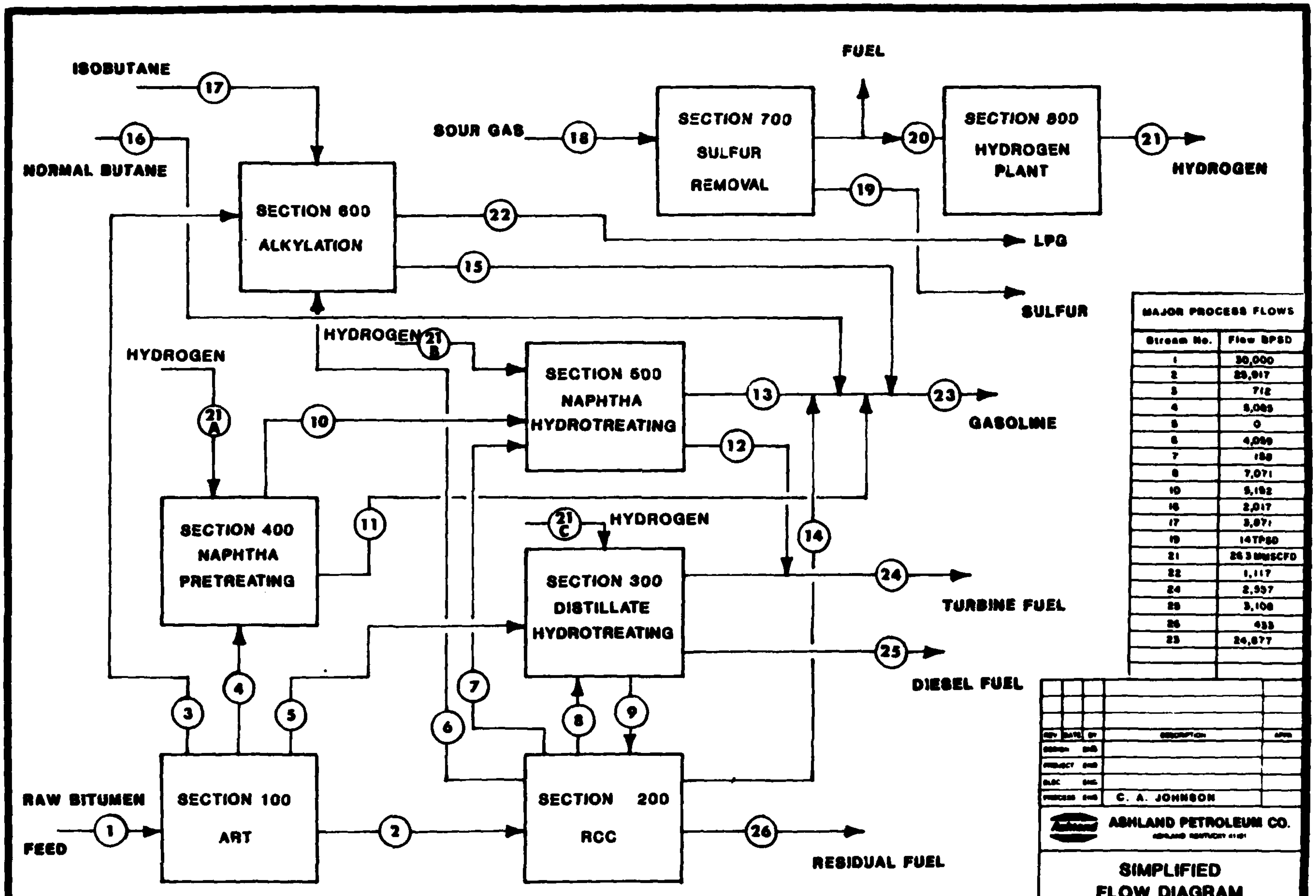
BASE CASE

PRIME PRODUCT COST DISTRIBUTION
30,542 BPCD PRIME PRODUCTS

COST ELEMENT	$/BBL PRIME PRODUCTS	% OF COST
START-UP	0.21	0.5
WORKING CAPITAL	0.34	0.8
BYPRODUCTS	(1.17)	(2.7)
FIXED COSTS	2.15	4.9
INCOME TAXES	3.36	7.8
UTILITIES	2.39	5.5
CAPITAL	5.92	13.6
RAW MATERIALS	30.39	69.6
TOTAL	43.59	

( ) Denotes Credit





MAJOR PROCESS FLOWS	
Stream No.	Flow BPSD
1	30,000
2	25,917
3	712
4	5,085
5	0
6	4,089
7	158
8	7,071
10	5,192
16	2,017
17	3,871
19	14TPSD
21	26.3 MMSCFD
22	1,117
24	2,937
25	3,106
26	433
23	24,877

FIGURE 12

CASE 8 : SUNNYSIDE BITUMEN BASE CASE WITH STEAM REFORMING

TABLE 29

SUNNYSIDE OIL

FEEDSTOCK VALUATION - 1983 PRODUCT PRICES

FEEDSTOCKS, BPCD	
Bitumen	29,970
IC_4	3,495
NC_4	1,899
TOTAL	35,364
PRODUCTS, BPCD	
LPG	981
Regular Gasoline	1,583
Unleaded Gasoline	21,409
JP-4	898
JP-8	6,533
TOTAL	31,404
CAPITAL INVESTMENT, MM$	368
FEEDSTOCK VALUE, $/BBL.	19.80

hydrogen content material with a very high carbon residue. Base properties of this material indicate a very aromatic character. Due to high sulfur levels, partial oxidation was used for hydrogen production.

This material resulted in the lowest product yield, 29M BPD from 36 M BPD of total feed, of any of the feedstocks evaluated. The high sulfur, high carbon content of the material was the key to these low yields and low thermal efficiency (73%). An overall product cost of $48.20/bbl, (Table 30) and an alternative feed value of $14/bbl (Table 31), suggest that this material is marginal for producing turbine fuel from the ART/RCC process combination. The overall flow diagram is summarized in Figure 13.

Feedstock Comparison

In terms of overall product cost/feed values, the relative ranking of these materials (listed in decreasing order of quality), for this process and these assumptions, is:

Hondo

Westken, Sunnyside

Tar Sands Triangle

The Westken and Sunnyside materials are judged equivalent, since minor basis changes were shown to change their relative values. None of these materials are competitive in present markets except at significant discounts from the $25/bbl base.

TABLE 30. TAR SANDS TRIANGLE RESULTS

TAR SANDS TRIANGLE OIL

BASE CASE

MATERIAL FLOWS

FEEDSTOCKS:	BPCD	% OF TOTAL INPUT
BITUMEN	29,998	84.1
ISOBUTANE	3,912	11.0
NORMAL BUTANE	1,762	4.9
TOTAL IN	35,672	100.0
PRODUCTS:		
LPG	1,117	3.1
GASOLINE	21,318	59.8
JP-4	2,371	6.6
DIESEL, DF-2	4,566	12.8
TOTAL OUT	29,372	82.3
PRIME PRODUCT YIELD, VOL.%		79
ESTIMATED THERMAL EFF. NET %		73

TAR SANDS TRIANGLE OIL
BASE CASE

INVESTMENT DATA

FIXED CAPITAL, MM$	394
WORKING CAPITAL, MM$	25

INVESTMENT DISTRIBUTION, % OF TOTAL:

ART	25.2
RCC	19.4
ALKYLATION	3.0
HYDROGENATION	9.6
HYDROGEN PLANT	6.8
SULFUR RECOVERY	2.0
OFFSITES	34.1

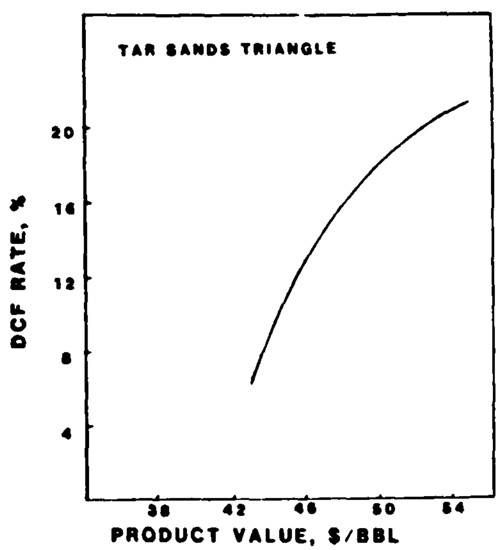
TAR SANDS TRIANGLE OIL

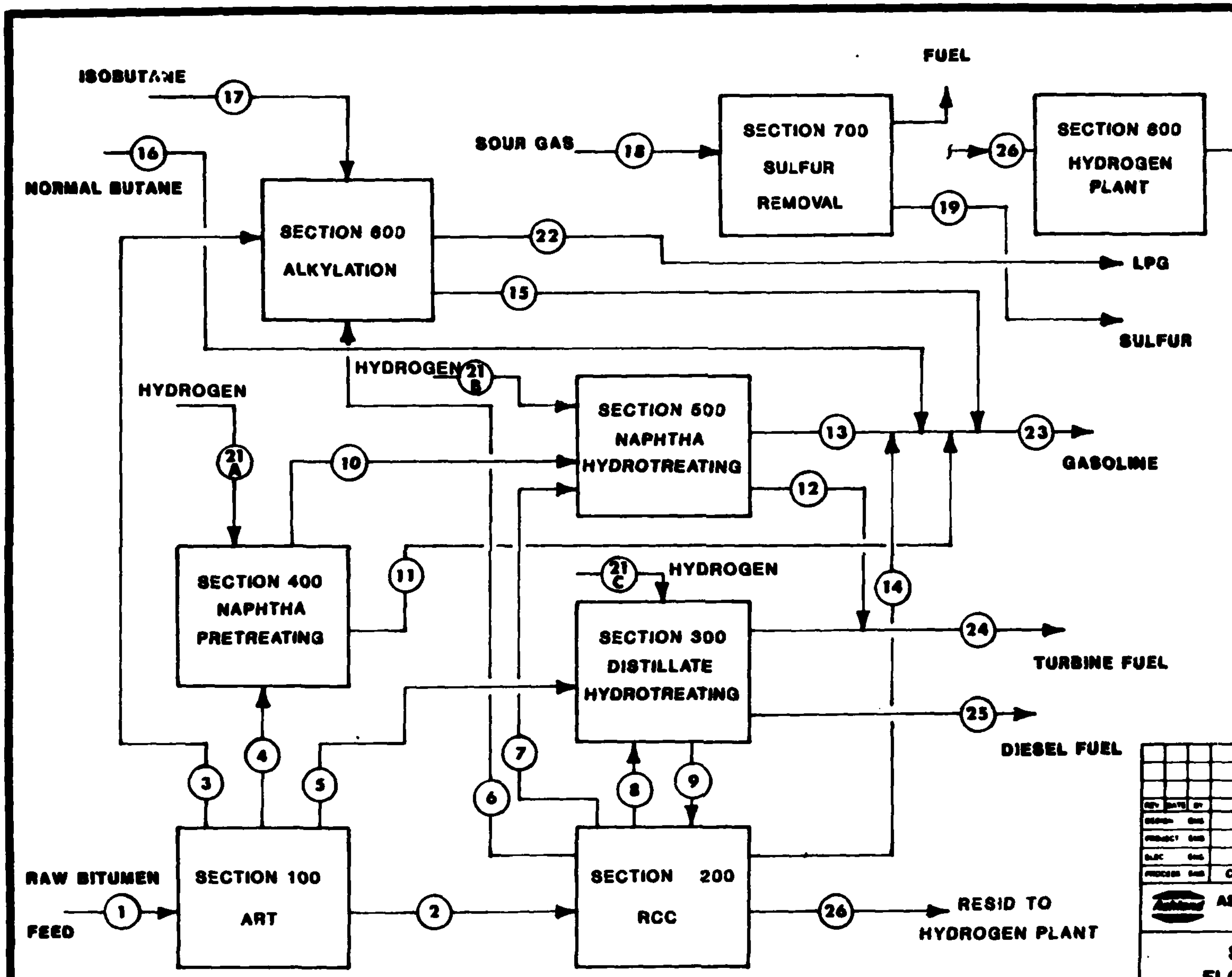
BASE CASE

PRIME PRODUCT COST DISTRIBUTION
28,255 BPCD PRIME PRODUCTS

COST ELEMENT	$/BBL PRIME PRODUCTS	% OF COST
START-UP	0.25	0.5
WORKING CAPITAL	0.37	0.8
BYPRODUCTS	(1.29)	(2.7)
FIXED COSTS	2.59	5.4
INCOME TAXES	3.95	8.2
UTILITIES	2.73	5.7
CAPITAL	6.96	14.4
RAW MATERIALS	32.64	67.7
TOTAL	48.20	

( ) Denotes Credit





MAJOR PROCESS FLOWS	
Stream No.	Flow BPSD
1	30,000
2	20,719
3	1,214
4	4,482
5	3,190
6	3,188
7	1,779
8	5,184
10	4,846
16	1,762
17	3,912
18	130 TPSD
21	24.3 MMSCFD
22	1,117
23	21,318
24	2,371
25	4,866
26	1,221

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ASHLAND PETROLEUM CO.

SIMPLIFIED
FLOW DIAGRAM
BITUMEN REFINING

SCALE NTS
DATE 3/12/84

FIGURE 13

CASE Y : TAR SANDS TRIANGLE BASE CASE WITH PARTIAL OXIDATION

TABLE 31

TAR SANDS TRIANGLE

FEEDSTOCK VALUATION - 1983 PRODUCT PRICES

FEEDSTOCKS, BPCD	
Bitumen	29,998
Isobutane	3,881
Normal Butane	1,811
TOTAL	35,690
PRODUCTS, BPCD	
LPG	1,038
Regular Gasoline	4,606
Unleaded Gasoline	16,943
JP-4	106
JP-8	6,542
TOTAL	29,235
CAPITAL INVESTMENT, MM$	389
FEEDSTOCK VALUE, $/BBL	14.20

Process Evaluation

Overall, the process evaluation indicates that the ART/RCC route should be applicable for at least three of the four feedstocks evaluated. For the more refractory materials such as Tar Sand Triangle bitumen, hydroprocessing may be more desirable. This is particularly true for the combination of high sulfur and high carbon content.

During the evaluation, and observation of initial operations at Catlettsburg, the desirability of reducing the total distillate feed to the ART unit became obvious. Phase II evaluations will better define process direction.

The major weakness in the evaluation of these materials is the lack of experimental data for use in the model. Phase II operations have been, and should be, designed to fill these data needs.

Overall economics of the process are thought to be representative for comparison of these materials. The dollar magnitude of capital expenditure projected by the model is probably low due to the lack of a direct charge for feed/product tankaoe and a probable undercharge for process waste treatment. These factors are very site and project specific, however, and are better defined at the engineering design stage. The costs used are based on actual

construction experience and should be the best available for relative rankings of these materials. Comparison to other processing schemes should only be made with these factors in mind.

Finally, Table 32 summarizes the objectives and goals originally defined for this program. All major goals were met by this analysis, and the framework required for further work was developed.

TABLE 32

CHECKLIST OF PHASE I

OBJECTIVES AND GOALS

- ✓ DETERMINE YIELDS AND COSTS OF TURBINE FUELS AVAILABLE
- ✓ DETERMINE POTENTIAL CHEMICAL AND PHYSICAL QUALITIES OF FUELS
- ✓ OPTIMIZE THE PROCESSING SCHEME
- ✓ ACHIEVE AT LEAST 70% ENERGY EFFICIENCY
- ✓ LIMIT RESIDUAL FUEL TO LESS THAN 10% OF PRODUCTS
- ✓ DEVELOP AN ECONOMIC MODEL OF THE PROCESS
- ✓ DETERMINE ECONOMIC EFFECT OF VARYING FUEL QUALITY

VII. CONCLUSIONS

Resource

- World resources of bitumen and heavy oil are significant, potentially equalling known conventional oil in-place.
- United States deposits are relatively small compared to Canadian and Venezuelan resources, but are significant in terms of magnitude.
- The primary US heavy oil reserves are in California.
- The major US bitumen reserves are in Utah.

Process Analysis

- The ART/RCC process selection should be valid for intermediate quality stocks - 10-20° API, moderate carbon content.
- Optimum product slates from this process provide gasoline as the primary product, although production of up to 50 volume percent turbine fuel is readily accomplished at relatively low incremental cost.
- Process configurations will, in particular, be driven by feedstock sulfur content and product value assumptions.
- On-site syncrude production at 7500 BPCD feed is not recommended in this configuration.
- Turbine fuel products from the process are predicted to be predominately naphthenic, with low sulfur content, variable aromatics, and a hydrogen content lower than conventional fuels. The freeze point should be good, and stability excellent.

Feedstock Evaluation

- The Hondo oil is the superior material evaluated in spite of its high sulfur levels.

- The Westken and Sunnyside bitumen appear to be of approximately equal value, depending on the assumptions and bases used.

- The Tar Sands Triangle material is the poorest feedstock of those analyzed in this process due primarily to sulfur and carbon residue.

- These materials are not competitive in present markets at $25/barrel, even if processing capabilities were available.

- More refractory materials, possibly including the Tar Sands Triangle product but definitely including materials such as the San Miguel Tar, are probably better suited to hydroprocessing.

VIII. RECOMMENDATIONS

- There is a strong driving force to reduce total virgin material fed to the ART unit. Separations, including vacuum fractionation, solvent extraction, etc., should be tested.
- The effects and fate of salt content in the ART feed is presently unknown. The need for desalting must be evaluated experimentally.
- Direct use of a portion of the asphaltene concentrate as boiler fuel (in the limestone boilers) or for fuel generation could improve process economics.
- Optimization of ART diluent may be of major economic impact.
- Utilization of process-derived hydrogen donor streams may be beneficial to yields in either the ART, the RCC, or both.
- Present model information, developed by estimates, should be replaced as much as possible by experimental data.

APPENDIX A

SUMMARY OF ESTIMATED OPERATING CONDITIONS AND MATERIALS FOR MAJOR PROCESS MODULES

Design Basis Only

	Conditions	Cost Basis Major Vessel Materials
ART:	920-980°F 15 PSIG 2-6 Sorbent:Oil Ratio (wt) ARTCAT Sorbent	Cold Wall Carbon Steel Refractory Lined
RCC:	940-1000°F 15 PSIG 6-10 Catalyst:Oil Ratio (wt) Approved RCC Catalyst	Cold Wall Carbon Steel Refractory Lined
Naphtha Pretreating:	400-500°F 800 PSIG 3-4 LHSV Commercial Ni-Mo HDS Catalyst	SS Type 316, Clad where appropriate
Naphtha Hydrotreating:	630-680°F 800 PSIG 1-3 LHSV Commercial Ni-Mo HDS Catalyst	SS Type 316, Clad where appropriate
Distillate Hydrotreating:	675-750°F 1600 PSIG 0.75-1.5 LHSV Commercial Ni-Mo HDS Catalyst	SS Type 316, Clad where appropriate

NOTE: Alkylation, Sulfur Recovery, and Hydrogen Plants are conventional equipment provided on a module basis, not otherwise specified.

APPENDIX B

PHASE II EXPERIMENTAL PLAN

The Phase II operating plan has been developed based on the needs defined during Phase I. Major questions include:

- o Impact of salt content
- o Optimum separation prior to ART
- o Optimum combination of ART/RCC
- o Optimum diluent, type and quantity
- o Actual vs. correlated data
- o Process characteristics and projections
- o Material properties

These questions will be addressed under the following overall objectives:

- o Characterize feedstocks
- o Determine process variable response
- o Produce inspection samples of turbine fuel

These objectives will be attained by performance of seven major WBS elements, Table A-1. These elements include laboratory preparations and analyses to test the effect of feed properties and process variables during the upgrading of these stocks to finished products.

These data will be used to set conditions for preparing sample products for evaluation and to update the process

TABLE A-1

PHASE II LABORATORY SAMPLE PRODUCTION

2.1 Determine Process Variables

- 2.1.1 Develop Metals Removal Data
  - 2.1.1.1 Test/Select Adsorbent for Feedstock 1
  - 2.1.1.2 Test/Select Best Diluent
  - 2.1.1.3 Evaluate Other Feedstocks Over Best Adsorbent
  - 2.1.1.4 Demetallize Large Size Sample
- 2.1.2 Develop RCC Response Data
  - 2.1.2.1 Evaluate RCC Response of One Untreated Feed
  - 2.1.2.2 Test/Select Catalyst for One Treated Feed
  - 2.1.2.3 Evaluate Other Feedstocks Over Best Catalyst
  - 2.1.2.4 Evaluate Effect of Hydrogen Addition
- 2.1.3 Develop Hydrotreater Parameter Variation Data

2.2 Characterize Feedstocks

- 2.2.1 Characterize Feedstock 1
- 2.2.2 Characterize Feedstock 2
- 2.2.3 Characterize Feedstock 3
- 2.2.4 Characterize Feedstock 4

2.3 Laboratory Sample Production

- 2.3.1 Metals Removal
- 2.3.2 Syncrude Preparation
- 2.3.3 Final Sample Preparation

2.4 Develop Phase III Operating Plan

- 2.4.1 Define Feedstock to be Used
- 2.4.2 Define Operating Conditions
- 2.4.3 Document Detailed Plan

2.5 Upgrade Process Model

2.6 Write Interim Technical Report

2.7 Program Management

model. Finally, a technical plan for pilot plant preparations in Phase III will be developed.

WBS 2.1. Determination of Process Variables. Bench scale laboratory equipment will be used in blocked out operation to develop the data pertaining to process response by the feedstocks under study.

2.1.1. Metals Removal

Metals, contained in varying amounts in heavy feedstocks, cause catalyst deactivation and poisoning and can also catalyze unwanted reactions such as dehydrogenation. These metals along with some of the carbon residue are removed in this step. The major factors for consideration are:

- Adsorbent
- Diluent
- Feedstock Distillation
- Process Severity

The use of a diluent produced downstream will be explored primarily as a viscosity reducing aid, especially when any light ends are removed from the feedstock. Four feedstocks will be tested.

2.1.2. RCC Response

The RCC (Reduced Crude Conversion) process will be used in

boiling range conversion or cracking of the heavy materials into a suitable stock for further treatment. Yield distribution and product properties will be determined from data collected using laboratory equipment. The following will be included in the study:

- o Catalyst Selection
- o Effect of Pretreatment
- o Effect of Hydrogen Donor
- o Process Severity

Approximately three catalysts will be tested at three or more sets of process conditions. Untreated and demetallized feeds will be compared and response variables will be determined for four feedstocks.

2.1.3. Hydrotreater Variable Study

When the desired boiling range is obtained in the RCC unit the products tend to be highly aromatic and olefinic, a desirable quality for gasoline but a negative property for turbine fuel. Final hydrotreatment will be performed in laboratory universal reactors to determine:

- o Process Variable Effects
- o Hydrogen Consumption
- o Aromatic Saturation
- o Product Quality

Process variable studies will be accomplished over a standard hydrotreating catalyst of good aromatic saturation activity

and the resulting products will be tested against appropriate fuel specifications.

WBS 2.2. Characterization of Feedstocks

Four feedstocks will be tested in this phase to determine how differences in properties affect the processing scheme. In this section the feedstocks will be analyzed then distilled into smaller fractions to be analyzed. By comparing properties of these fractions with those of typical petroleum fractions an idea of the processing response will be obtained. This section will be addressed concurrently with section 2.1 above. These feedstocks were on hand as of 4/2/84, and and are inventoried in Table A-2.

WBS 2.3. Laboratory Sample Preparation

A blocked out laboratory preparation of samples of the final turbine fuel will be accomplished by using a combination of steps determined from 2.1 above. The four feedstocks will be processed through the metals removal, RCC and hydrotreating steps separately to produce fuel samples. Final fractionation will produce the desired JP-4 or JP-8 fuel. We plan to provide samples of JP-4, JP-8, gasoline, diesel fuel, and residual fuel under this WBS element.

WBS 2.4. Phase III Plan

The operating plan for Phase III will be developed from data

TABLE A-2

FEEDSTOCK INVENTORY

SOURCE	DRUMS
WESTKEN BITUMEN*	27
HONDO HEAVY OIL	30
SUNNYSIDE BITUMEN	8
SAN ARDO HEAVY OIL	28

*BASE STOCK FOR PROCESS DETERMINATIONS

gathered in Phase II. This plan will include instructions for operating the pilot plant based on Phase II results. Also included will be plans for scheduling, managing, and reporting Phase III.

WBS 2.5. Process Model Update

The model which was developed in Phase I will be updated according to results obtained in Phase II. This part of the program will continue in Phase III when the model will be finalized.

WBS 2.6. Interim Technical Report

The Interim Technical Report will be a compilation of results, conclusions, and recommendations derived from the activities of Phase II.

WBS 2.7. Program Management

Concurrent program management will be required for control of costs, scheduling manpower, and assuring completion of the program. Monthly reports, cost reporting and the interim technical report will be part of this section.

The program schedule is shown in Figure A-1. Month 1 is defined as April, 1984. Schedule attainment will be determined from the detailed management plan submitted separately.

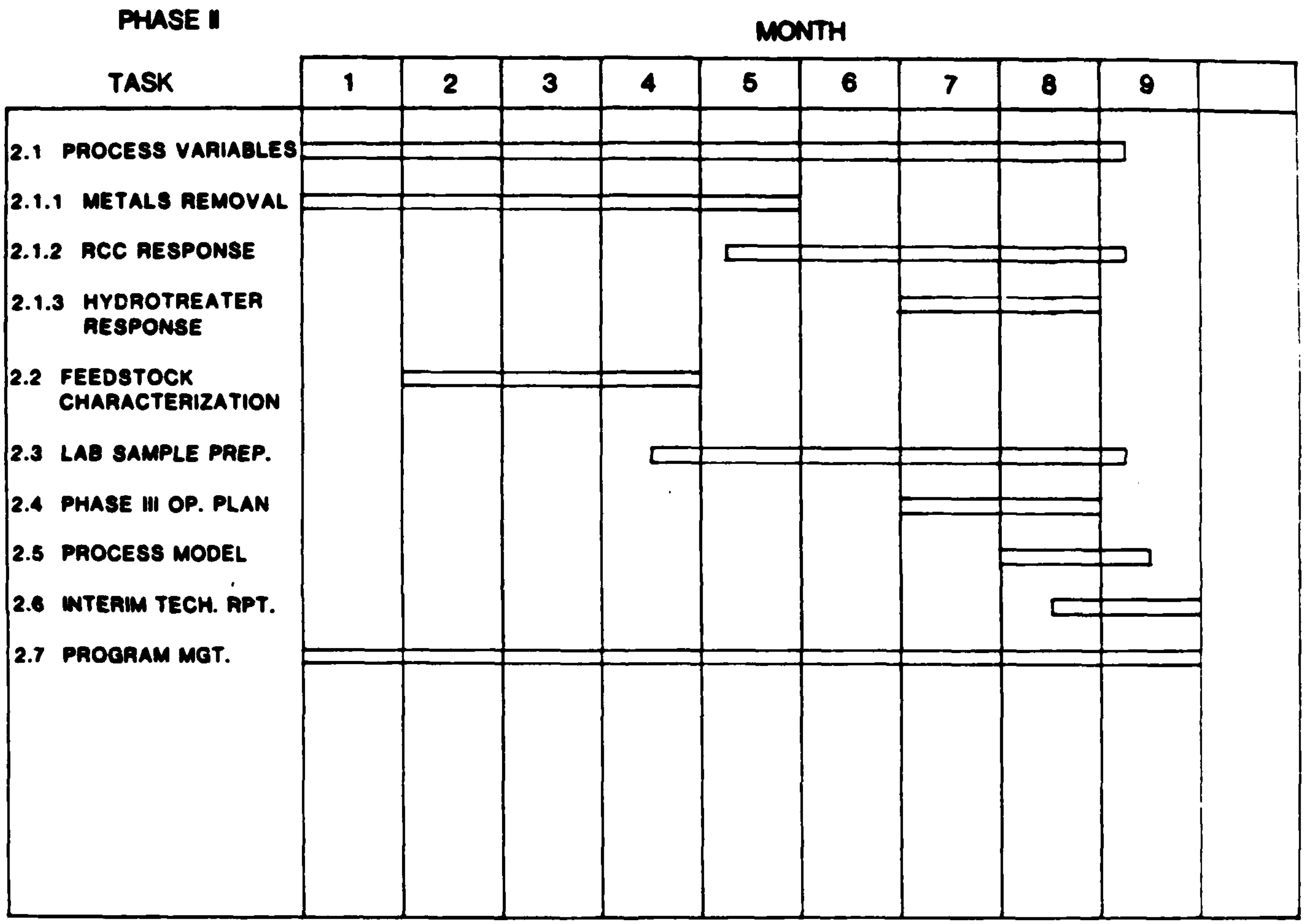

FIGURE A-1

TURBINE FUELS FROM TAR SANDS AND HEAVY OILS

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